5842

21 Processing and Utilization

T. L. Mounts
Northern Regional Research Center
Peoria, Illinois

W. J. Wolf
Northern Regional Research Center
Peoria, Illinois

W. H. Martinez
USDA-ARS
Beltsville, Maryland

The soybean [*Glycine max* (L.)] has long been recognized as a valuable component of medicine, food, and feed in ancient China. It was first cultivated in the USA in 1766 to provide the necessary ingredients to make soy sauce and vermicelli for the English market (Hymowitz and Harlan, 1983). This initial activity ceased with the demise of its promoter, Samuel Bowen; and interest in the soybean lay essentially dormant for a century.

Several events—the Perry Expedition (1853–1854), development of the State Agricultural Experiment Station and Extension systems in the USA, and the Chinese-Japanese War (1894–1895) which enhanced trade and access to soybean seed—were critical to the expanded production and utilization of the soybean in the USA (Probst and Judd, 1973). The first USDA bulletin devoted entirely to soybean and their use as a forage crop was issued at the turn of the century (Williams, 1899). From an estimated production of 20 000 ha in 1907, soybean hectarage for hay and silage steadily increased to 1.9 million ha by 1940.

Other contemporary and subsequent events shifted the mode of utilization into new and different forms. Soybean seeds imported from Manchuria by European countries (1900–1910) were successfully used as a source of oil in soap manufacture; World War II greatly increased demand for fats and oils; and the effect of the boll weevil on cottonseed production created a need for an alternate oilseed crop. By the mid-1930s, defatted soybean meal had also become an accepted protein ingredient in livestock and poultry production. These events reversed the U.S. position of net importer of oil, meal, and bean in the period 1900 to 1918, to one of net exporter of soybean meal in the late 1930s. By 1941, soybean hectarage

Soybeans: Improvement, Production, and Uses, 2nd ed.—Agronomy Monograph no. 16.

harvested for processing into oil and meal (2.4 million ha) exceeded the hectarage providing forage silage and seed (2.2 million ha). Currently, the majority of the more than 28 million ha of soybean crops cultivated in the USA are harvested for domestic or foreign processing into meal and oil products (Table 21-1).

21-1 SOYBEAN OIL

Initially, growth of the U.S. soybean industry was influenced more by the shortage of oil and its relatively high price than the need for protein. In the 1920s, the oil was used mostly in soaps, paints, and varnishes. Use of soybean oil in food was restricted for a considerable period because of flavor stability problems (Dutton, 1981).

Deficiencies in the performance of soybean oil as an industrial drying oil combined with strong competition from synthetic resins and detergents materially limited the size of the industrial market (Smith and Circle, 1972). Efforts to develop new industrial uses began at the U.S. Regional Soybean Industrial Products Laboratory, organized in 1936, and continued later at the Northern Regional Research Laboratory (1940). Cost of the raw material relative to petroleum continued to be a dominant factor. Despite the development of new end uses such as speciality nylons, high-pressure lubricants, plasticizers and coatings, domestic use of soybean oil for industrial products has remained essentially constant at about 2% of supply or 90 700 t since 1960 (USDA, 1984a).

As interest in industrial use declined, demand for edible fats and oils rose, stimulating interest in improving soybean oil quality. Though the

Table 21-1. Soybean supply and use (USDA, 1950-1982).

	Supply			Utilization		
Year	For all purposes	Harvested for hay	Harvested for bean	Total production for bean†	Processed for oil and meal	Exports
	10^3 ha			10^6 t		
1929	983	—‡	287	0.2	0.1	—
1939	3 874	1 859	1 748	2.4	1.6	0.3
1942	5 547	1 062	4 007	5.1	3.6	<0.1
1947	5 286	523	4 622	5.1	4.4	0.1
1952	6 463	439	5 846	8.1	6.4	0.9
1957	8 520	180	8 447	13.1	9.6	2.4
1962	11 509	184§	11 181	18.2	12.9	4.9
1967	16 514	—	16 106	26.6	15.7	7.3
1972	18 981	—	18 502	34.6	19.7	13.0
1977	23 886	—	23 421	48.1	25.2	19.1
1982	29 226¶	—	28 667	60.7	30.2	24.6

†Difference between "total" and sum of "processed" and "exports" accounted for as seed, feed, and residual.
‡Data not available.
§Minimal hectarage reported as part of "other hay" category after 1964.
¶Preliminary data.

exigencies of World War II forced increased use of soybean oil in margarine, in certain instances as much as 30%, quality remained a problem. Through a unique collaboration begun in 1946 of government, academic, and industrial research organizations fostered by the National Soybean Processors Association, technologies were devised to make soybean oil the leading edible oil in the USA (Dutton, 1981).

The relative market share held by soybean oil in the most recent decades is indicated in Tables 21–2, 21–3, and 21–4. Since 1960, soybean oil's share of the edible oil products market has increased from 54 to 76% (Table 21–2). This increase occurred primarily at the expense of cottonseed oil and lard for which price, availability, improved processing technology, and nutritional considerations (cholesterol and polyunsaturation) were contributing factors.

Within the major classes of edible products (Table 21–3), use of soybean oil in baking and frying fats, salad and cooking oils, and margarine has changed from a 4-3-3 distribution in 1960 to a 3-5-2 distribution, respectively, in 1982–1983.

As documented in Table 21–4, soybean oil held over 80% of the margarine market by 1960. But the 40% growth in this market since 1960 must be considered moderate when compared to a 90% increase in utilization of baking fats and oils, and 320% increase for salad and cooking

Table 21–2. Market share of selected fats and oils in edible oil products in the USA. (USDA, 1984a)

Item	1960	1965	1970	1975	1980–1981†	1982–1983†
	%					
Soybean oil	54	56	66	66	72	76
Cottonseed oil	22	19	10	6	5	5
Corn oil	5	‡	‡	5	5	5
Peanut oil	1	1	2	1	1	1
Lard	9	7	6	2	3	2
Edible tallow	5	5	6	6	6	5
Coconut oil	3	3	4	1	3	3
Palm oil	‡	‡	‡	7	2	2

†Census started reporting annual tables on a marketing year (October–September) basis beginning in 1978/1979.
‡Census data withheld to avoid disclosing figures for individual companies.

Table 21–3. Distribution of soybean oil as used in various edible oil products in the USA. (USDA, 1984a)

1960	1965	1970	1975	1980–1981†	1982–1983†	
	%					
Baking and frying fats	37	35	36	30	31	32
Salad and cooking oils	28	37	40	46	49	50
Margarine	34	27	23	24	19	17
Other edible products	1	1	1	‡	1	1

†Census started reporting annual tables on a crop year (October–September) basis in 1978
‡Less than 0.5%.

Table 21-4. Soybean oil consumed in end products and percent of total fats and oils used in the USA (USDA, 1984a).

Item	1950		1960		1965		1970		1975		1980–1981†		1981–1982†	
	10^3 t	%	10^3 t	%	10^3 t	%	10^3 t	%	10^3 t	%	10^3 t	%	10^3 t	%
Baking and frying fats	361	48	530	51	667	53	990	61	918	54	1213	63	1357	67
Salad and cooking oils	156	27	402	46	709	56	1120	73	1375	76	1917	80	1981	80
Margarine	208	50	501	81	504	72	639	79	711	82	756	82	781	86
Other edible products	—‡	—	12	10	16	9	17	8	10	5	20	11	23	13
Edible total	725	23	1446	54	1896	56	2766	66	3014	66	3906	72	4142	74
Inedible	140	7	99	5	116	5	101	4	83	4	92	4	92	4
Total	865	17	1545	34	2012	36	2867	44	3097	46	3998	50	4234	53

†Census started reporting annual tables on a crop year (October–September) basis in 1978.
‡Included in "salad and cooking oils."

oils by 1981 to 1982 (USDA, 1984a). The increased utilization of salad and cooking oils, coupled with a rapid increase in soybean oils's share of this market (46%, 1960; 80%, 1981/1982), produced an exceptional rate of increase in tonnage of soybean oil consumed by this market area since 1960.

Future rate of growth for soybean oil in domestic edible markets will be moderated by diminished population growth. Maintenance of current market share will depend upon nutritional concerns with total calorie consumption. Export demand will be subject to pressure from the anticipated rapid expansion in availability of palm and palm kernel oils and the growing ability of other nations to meet and exceed their domestic food needs. Future increase in soybean oil utilization may well depend upon expanded industrial use in areas such as grain dust suppressants, pesticide application, and the ability to cost-effectively convert this renewable resource to chemical feedstocks.

21-2 SOYBEAN PROTEIN

Soybean meal plays a key role as a protein ingredient in feeds in the USA. About 16.2 Tg were forecast to be available for consumption as feeds in 1984; consumption by animal classes was forecast as follows (USDA, 1984b):

Class	Tg	Percent
Poultry	7.2	46
Swine	4.4	32
Beef	1.9	9
Dairy	1.7	9
Others	1.0	4
Total	16.2	100

Poultry feeds are the largest outlet for meal followed by swine (*Sus* spp.) feeds; the two account for 78% of total usage. Soybean meal has been estimated to make up more than 90% of the oilseed meals consumed in poultry feeds. Smaller quantities of soybean meal are fed to beef and dairy cattle (*Bos* spp.). Pet foods are another market for soybean meal.

Production of edible protein products is small as compared to soybean meal for feed uses. No official statistics for soy flour, concentrate and isolate production are kept, and individual producers consider their own production figures as proprietary information. Estimates obtained from industry sources for 1982 are shown in Table 21-5. There has been no significant change in recent years. Flours and grits were produced in the largest quantities estimated to be 159 000 t; concentrates, isolates, and textured flours were manufactured at 36 000 to 43 000 t each; textured concentrates represented only 4000 t. Selling prices for the protein products are also included in Table 21-5. Prices of concentrates and isolates

Table 21-5. Production estimates for edible soybean protein products in the USA for 1982.

Product	Minimum protein content†	Annual production	Selling prices‡
	%	10^3 t	$/kg
Defatted flours and grits	50	159	0.22-0.24
Concentrates	70	36	0.92-0.95
Isolates	90	41	2.20-2.42
Textured flours	50	43	0.66
Textured concentrates	70	4	1.21

†Dry basis.
‡January 1985 prices.

relative to flours and grits reflect the added costs of processing involved in their manufacture.

21-3 SOYBEAN PROCESSING

Soybean is processed to yield oil and meal by a hexane extraction process (Becker, 1978). In recent years, there has been a trend towards increasing the capacity of soybean processing plants. In 1978, 50% of the processing plants had < 900 t day^{-1} capacity (Mogush, 1980), while by 1982, 76% had capacities of > 900 t day^{-1} (American Soybean Association, 1983). On the average, about 80% of the U.S. capacity has been used annually (Mogush, 1980).

21-3.1 Traditional Extraction Technology

Although large quantities of soybean are received at the extraction plants at harvest time, purchase and receipt of bean continue throughout the year. The soybean are cleaned and dried if above about 13% moisture (w/w) and stored in large concrete silos (Fig. 21-1); most processors prefer to "age" freshly harvested soybean for about 21 days to facilitate processing. Belt conveyors and bucket elevators bring the soybean into the plant where they are collected in storage bins. Prior to dehulling, the soybean pods are dried to 9.5 to 10.5% moisture (w/w) and then tempered for several days. Before being fed into the cracking rolls, the soybean are cleaned and passed over a magnet to remove stray metal. A shaker screen follows the cracking rolls, where the fines drop through and the hulls are removed by fan aspiration. The cracked bean is conditioned to 10 to 11% moisture and 74 to 79°C (165-175°F) in a steam-jacketed cooker, a vertical-stack type or a rotary steam-tube dryer type. Moisture as live steam or water spray is added to the conditioner if necessary. Flaking of the bean is accomplished in a roll stand consisting of a pair of smooth-surface rolls regulated to produce flakes about 0.254-mm (0.010 inch) thick. The

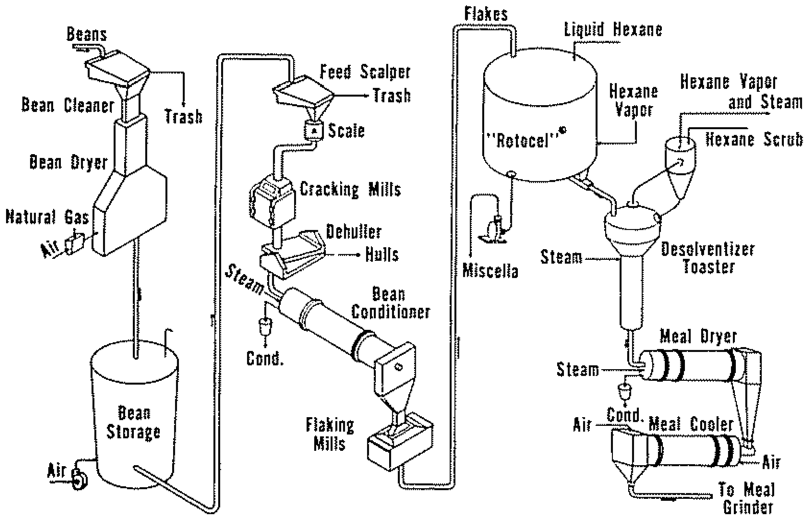

Fig. 21-1. Flow chart for the solvent extraction of soybean. Courtesy, Dravo Corporation.

flakes are then transported to the extractor by mass-flow type enclosed conveyors designed to minimize flake breakage.

Percolation type extractors are used for the hexane extraction of soybean. The liquid solvent or miscella (solvent containing dissolved oil) is pumped over a bed of flakes, percolates down through the bed, and leaves at the bottom through a perforated plate, mesh screen, or wedge wire screen bar system countercurrent to the movement of the flakes. Some of the types of percolation extractors are rotary cells, chain and basket, perforated belt, chain conveyor, and filter. With one rotary type the cells rotate in a horizontal plane and fresh solvent is pumped onto flakes at the end of the extraction cycle; as extraction proceeds the miscella becomes richer in oil. The extracted flakes are allowed to drain before being dropped into the discharge hopper.

The extracted flakes contain about 30 to 35% hexane, 7 to 8% water, and 0.5 to 1.0% oil. For processing into livestock meal, solvent is reclaimed from the flakes in the desolventizer-toaster (D-T) unit. Description of the D-T operation and further processing of the defatted flakes into edible soy protein proteins is discussed later (section 21–7).

The miscella leaving the extractor contains about 25 to 30% oil; it is first filtered to remove suspended fines, and then enters a series of evaporator stages for reclamation of the solvent. The first stage evaporator is heated with vapors from the DT and gives a miscella containing 65 to 78% oil; the second stage evaporator yields 90 to 95% oil content. Vapors from the two evaporator stages pass to condensers, and the recovered hexane is recycled to the extractor. Final solvent removal is accomplished in the oil stripper, a steel cylindrical vacuum column in which live steam flows upward countercurrent to the flow of oil. The oil, essentially free of solvent, is cooled to ambient temperature and pumped to storage.

21–3.2 New Developments

The introduction of fluidbed driers for soybean drying, dehulling, and conditioning is estimated to have reduced heat requirements to 50% of the traditional soybean drying and preparation process (Florin and Bartesch, 1983). The soybean are taken from storage, cleaned, and introduced into the fluidbed drier. Hot air is used as the fluidization gas and the soybean are quickly heated to a surface temperature of 75 to 92°C. With this heat treatment the hulls are loosened from the cotyledons and cracked open. The product stream proceeds through cracking rolls and hammer mills, to halve the bean and free the detached hulls by discharge air and the halved soybean are then conditioned. On leaving the fluidbed conditioner, the bean halves continue through cracking rolls and flakers to the extraction plant. In this process the soybean are only heated once in the drier and retain heat throughout to the extractor. The drying rate can be varied by adjustment of the temperature of the fluidbed and this flexibility allows direct dehulling of freshly harvested soybean. Use of fluidbed technology can reduce the drying and tempering time from 48 to 72 h to 10 to 20 min.

Another system for the drying and preparation of soybean is currently under study and is known as MIVAC drying (microwave vacuum) (Moore, 1983). This system uses electrical energy for drying and conditioning; cracking and dehulling proceed according to conventional methods and the cracked, dehulled soybean go directly to the flaker. The air used in the dehulling process is heated by the waste heat generated during production of the microwave energy.

Pretreatment of both whole soybean and flakes has been proposed for the inactivation of enzymes prior to oil extraction. The goal of such pretreatments is to improve crude oil quality to facilitate physical refining of the oil as an alternative to the traditional alkali refining process. Infrared (IR) heat treatment of whole soybean at 104°C for 5 min prior to bean preparation for oil extraction was adequate to achieve improved oil quality compared to untreated bean (Kouzek Kanani et al., 1984). Lipoxygenase activity was reduced to 0.5% of that found in untreated bean. The peroxide value determined for crude oil extracted from treated soybean was 0.6 cmol kg^{-1} compared to 2.8 cmol kg^{-1} of crude oil extracted from untreated soybean. This diminished oxidative deterioration was reflected in fewer off-flavors in treated-soybean oil compared to oil from untreated bean. Water-degummed oil from IR-treated soybean had a much lower P content (24 mg kg^{-1}) than that from raw soybean (185 mg kg^{-1}). This indicates an inactivation of phospholipase D by IR-treatment resulting in less formation of nonhydratable phospholipids during preparation and extraction of beans. The P content of oil from IR-treated soybean was reduced to 4 mg kg^{-1} by treating with 1% bleaching earth and was below the maximum (5 mg kg^{-1}) specified for steam refining. These laboratory tests suggest that IR-treatment of whole soybean may be successfully employed for enzyme inactivation prior to processing.

Moist-heat treatment of soybean flakes to inactivate phospholipase D has been commercialized as the ALCON process, an additional stage between conventional bean preparation and the extractor (Kock, 1983). In this process, the flakes are conditioned to moisture levels of 15 to 20% and a temperature of 95 to 110°C. The conditioned flakes are stirred while being tempered for a period of about 15 min. Stirring within the tempering equipment causes flake agglomeration, which gives the flakes a completely different granulated type structure having an increased bulk density. Finally, the flakes are dried and cooled to appropriate extraction conditions. Crude oil extracted from soybean flakes given this moist-heat treatment had a decreased amount of nonhydratable phospholipids which was confirmed by the low P content after water degumming.

The hexane used for oil extraction of soybean is a hydrocarbon fraction derived from petroleum having a boiling range of 63 to 69°C. It is an excellent solvent for vegetable oils and is essentially free of N-or S-containing compounds and unsaturated hydrocarbons (Mustakas, 1980). Interest in alternative solvents has increased due to disadvantages in the use of hexane. Being a petroleum product, hexane may be of limited availability in the future; it is extremely flammable and forms explosive mixtures with air. Hexane vapors are toxic, hence maximum concentrations in the workplace must be controlled. Recovery of hexane from oil and meal is energy intensive and incomplete, requiring that some of the solvent be continuously replaced.

Recently, Shell Development Company (Sullivan et al., 1982) and the Northern Regional Research Center (Baker and Sullivan, 1983) have conducted pilot-plant studies using isopropanol (IPA) as a solvent for extracting soybean. An IPA/water (88:12) azeotrope was employed near the boiling point (80.2 °C) and on cooling the miscella a phase separation occurs which allows recovery of the oil by nondistillation techniques in a phase separator. Residual IPA in the oil-rich phase is recovered in an oil stripper and a semi-refined oil is obtained that does not require degumming and produces smaller amounts of soapstock than hexane-extracted oil. The oil produced by IPA extraction has a lower phosphatide content than hexane extracted oil but is otherwise similar (Baker and Sullivan, 1983).

The IPA-extracted flakes leave the extractor with a higher solvent content than hexane extracted flakes. Mechanical screw pressing was used to reduce the IPA content prior to desolventizing and toasting. The resultant meal appears comparable to hexane processed meal for animal nutrition.

Workers at Texas A&M University have evaluated water as a solvent for oil recovery from soybean (Lawhon et al., 1981; Johnson and Lusas, 1983). In this process, finely ground soybean are mixed with water and the resulting slurry is centrifuged to yield an oil phase, an aqueous phase (containing protein, soluble sugars, and some oil), and an insoluble residue fraction (cell wall polysaccharides). The protein can be recovered by ultrafiltration followed by spray drying. This process has some disadvantages such as: low oil yields; the presence of oil in the protein fraction which may impart poor flavor stability; and a need to operate under more stringent sanitary conditions than are needed with hexane due to the potential for microbiological contamination.

Supercritical fluid (SCF) technology may offer a viable alternative to present extraction methods. Supercritical carbon dioxide (SC-CO_2) as a solvent for recovery of soybean oil has been evaluated recently on a laboratory scale (Friedrich et al., 1982). The SC-CO_2 extracted oil contains lower amounts of phosphatides and other nontriglyceride components than does hexane-extracted oil.

Defatted soybean meals with protein solubilities > 70% and with improved flavors were produced by SC-CO_2 extraction. Optimum extraction conditions were 82.8 MPa, 85°C, and 10.5 to 11.5% moisture (Eldridge et al., 1986). The usual grassy-beany and bitter flavors of hexane-defatted soybean flours were only minimally detected in optimally SC-CO_2 extracted materials. Meal characteristics were: Nitrogen Solubility Index, 62: Flavor Score, 7.2 (on a scale of 1–10, i.e., 1=strong, 10=bland); Lipoxygenase Units, 3 μm O_2 consumed min^{-1} mg^{-1} protein; trypsin inhibitor activity, 24.8 g kg^{-1}; and urease activity (pH increase), 2.1. Heat treatment of the defatted meal is required to inactivate urease and lower the trypsin-inhibitor activity. Disadvantages of the SC-CO_2 extraction technique are the expensive high pressure equipment and sophisticated technology required for implementation. If engineering problems can be overcome, however, this process may find application in the oilseed processing industry.

While several solvents have been examined, none has been developed to the point where it is used as a commercial replacement for hexane.

21–4 SOYBEAN OIL PROCESSING

Processing of soybean oil is designed to convert the crude oil as extracted from the bean into a finished product free of impurities and amenable to a variety of food formulations. Compositional analyses for crude and refined soybean oils are shown below (Pryde, 1980).

Composition	Crude oil	Refined deodorized oil
Triglycerides (%)	95–97	> 99
Phosphatides (%)	1.5–2.5	0.003–0.006
Unsaponifiable matter (%)	0.6	0.3
Plant sterols (%)	0.33	0.13
Tocopherols (%)	0.15–0.21	0.05–0.10

(continued on next page)

Continued.

Composition	Crude oil	Refined deodorized oil
Hydrocarbons (squalene) %	0.014	0.01
Free fatty acids (%)	0.3–0.7	< 0.05
Trace metals		
Iron (mg kg^{-1})	1–3	0.1–0.3
Copper (mg kg^{-1})	0.03–0.05	0.02–0.06

Traditionally, oils have been processed through stages of degumming, alkali refining, bleaching, and deodorization. Hydrogenation of the oil is practiced to improve stability and modify the physical nature of the oil from a liquid to a solid.

21–4.1 Degumming

The principal method of degumming employed in the USA is a batch treatment of the oil with 1 to 3% of water, based on oil volume (Carr, 1978). The mixture is agitated for 30 to 60 min at 70 to 80°C. The hydrated phosphatides and gums are separated by centrifuging. About 90% of the phosphatides are removed from the oil by water degumming (Myers, 1957). Although most of the remaining phosphatides are removed during alkali refining, vegetable oils often contain some phosphatides that are not removed by hydration. Beal et al. (1956) concluded that the residual P content of a satisfactorily refined oil should be between 2 and 20 mg kg^{-1} (0.06–0.6% phosphatide). Oils with P contents above this range were found to have decreased oxidative stability. Most commercially produced oils will contain < 5 mg kg^{-1} P.

21–4.2 Refining/Physical Refining

Refining of vegetable oils is practiced to remove free fatty acids, phosphatides and gums, prooxidant metals, coloring matter, insoluble matter, settlings, and miscellaneous unsaponifiable materials. The treatment has little effect on the triglycerides of the oil. The first step in the conventional process is called *caustic refining*. If a crude oil is to be caustic refined, it is usually treated with 300 to 1000 mg kg^{-1} of food-grade, 75% phosphoric acid at ambient temperature at least 4 h prior to the refining step, to increase the efficiency of phosphatide removal during caustic refining (Carr, 1978). Oil refining is usually a continuous process. A 15 to 20% sodium hydroxide (NaOH) solution based on the free fatty acid content of the oil plus 0.10 to 0.13% excess, is proportioned into the crude oil, mixed in a high shear in-line mixer, and then held for 3 to 15 min in a slow speed mixer. The soap-oil mixture is heated to 75 to 80°C and then separated into refined oil and soapstock by centrifuging. Refined oil is washed once or twice with 10 to 20% (w/w) of soft water at 90°C. Of all the unit processes, caustic refining has the most significant effect on oil quality and, if the oil is not properly refined, subsequent processing operations such as bleaching, hydrogenation, and deodorization will be impaired, and finished products will fail to meet quality standards. Protection of the oil from exposure to air is important during refining to minimize oxidative deterioration. Caustic refining is preferably conducted in hermetic disk-type, self-cleaning centrifuges, and completely closed systems where the oil has no contact with air from the moment it is pumped into the system until it leaves as a neutralized and dried oil. (Braae, 1976).

Crude oils processed from normal soybean refine satisfactorily and, after bleaching and deodorization, give high-quality soybean salad oils. Such oils are bland, or have midly beany, buttery, or nutty flavors and will receive flavor scores in the 7 to 8 range on a 10-point flavor intensity scoring scale (1 = extreme, 10 = bland). A flavor score of 6 is generally considered the breakpoint between satisfactory and unsatisfactory oils.

List et al. (1977) evaluated refining methods for improvement of flavor quality of oils extracted from field- and storage-damaged bean. They found that the strength or excess of alkali used had no significant effect on the flavor score of the oils, which were considered unsatisfactory as salad oils. Double-refining of phosphoric acid-degummed damaged bean oil showed some improvement over single-refining, but the flavor scores were merely borderline satisfactory and high refinery losses were anticipated in plant-scale operations.

Physical refining is an alternate process to caustic refining for removing the free fatty acids present in crude oil. Recent developments in the physical refining of edible oils, i.e., the removal of free fatty acids by steam distillation in a simultaneous deacidification-deodorization step, have required changes in degumming procedures. Degumming of the oil with phosphoric acid is an important pretreatment for physical refining (Sullivan, 1976). List et al. (1978b) stirred crude soybean oil with 0.2% (w/w) 85% phosphoric acid (H_3PO_4) for 15 min at 60°C, and then used centrifugation and decantation to separate gums. The degummed oil was washed twice with water (20% by weight), bleached with 0.5% earth at 105°C under vacuum, filtered, and then deodorized at 260°C, 1 mm of Hg for 1 h. The phosphoric acid-degummed oil was compared to a water-degummed oil, after both were steam refined, in organoleptic evaluations conducted as described by Moser et al. (1947, 1950, 1965). Evaluations of the freshly deodorized oils showed that the phosphoric acid degummed oil had significantly less intense flavors and a better flavor score than the water-degummed oil. The improvement in flavor score is attributed to enhanced Fe removal effected by the phosphoric acid pretreatment (List et al., 1978a). After water washing and bleaching, the phosphoric acid pretreated oil had an Fe content of 0.1 mg kg^{-1}, whereas the water-degummed oil contained 0.5 mg kg^{-1} of Fe. Iron is an active catalyst for oxidative deterioration of soybean oil, especially at deodorization temperatures (Beal et al., 1956).

21–4.3 Bleaching

Bleaching of alkali-refined oils removes entrained soaps and reduces color bodies in the oil; it is more appropriately referred to as adsorption treatment. Batch or continuous vacuum bleaching is generally practiced; this consists of agitation of the oil with 0.5 to 1.5% acid-activated earth at 90 to 95°C for 15 to 30 min at a high vacuum (3–10 mm of Hg absolute pressure) followed by filtration to give a clean, clear oil. Cowan (1966) reported the flavor evaluation of two deodorized soybean oils prepared in the same commercial plant. The bleaching step was included for one sample but omitted for the other. The bleached oil showed a significantly higher flavor score both initially and after accelerated storage. It has been suggested that bleaching removes peroxides and secondary oxidation products and that this added function gives the observed improvement in flavor scores (Wiedermann, 1981). Such removal is by processes involving chemisorption and subsequent chemical reaction on the surface of activated clays, i.e., decomposition and dehydration or pseudoneutralization of peroxides. Careful selection of the type of bleaching clay was shown to give a dramatic improvement in terms of peroxide reduction. Bleached oil having a peroxide value of 0.0 can be obtained for subsequent deodorization.

21–4.4 Deodorization

Deodorization is the last process step used to improve the taste, odor, color, and stability of the oil by removal of undesirable substances. All commercial deodorization, whether in continuous, semicontinuous, or batch units, is essentially a steam stripping of the oil for removal of free fatty acids and other volatile materials. Deodorization is conducted at 1 to 6 mm Hg and 210 to 274°C for 3 to 8 h in batch or 15 to 120 min in continuous or semicontinuous units, with 5 to 15%, or 1 to 5% stripping steam, respectively (Zehnder, 1976). The goal of deodorization is to produce a finished oil that has a bland flavor, a maximum free fatty acid content of 0.05%, and a zero peroxide value. The deodorization process will not produce a good quality finished oil unless the previous treatment of that oil was correct. In addition to the removal of free fatty acids and volatile odor compounds and the decomposition of peroxides, deodorization also reduces the tocopherol content of soybean oil by about one third. Tocopherols are natural antioxidants found in vegetable oils and contribute significantly to oxidative stability. Frankel et al. (1959) observed that at high concentrations of tocopherol, the synergistic effect between citric acid and tocopherol was decreased. They suggested that the residual tocopherol content in deodorized soybean oil was close to the optimum concentration for maximum oxidative stability. Citric acid (0.005 to 0.01% weight of oil) is added to the oil at the cooling stage in the deodorizer, to protect the oil against oxidation. Citric acid acts as a metal chelating agent and reduces the activity of prooxidant metals. Miyakoshi and Komoda (1978) evaluated the flavor of freshly deodorized oils, with varying concentrations of citric acid (8.5, 22.1, and 49 mg kg^{-1} added at 130°C during cooling. Oils were also evaluated after storage at 60°C and after 10-h exposure to fluorescent light. They found that the efficiency of citric acid is independent of concentration, and that as little as 10 mg kg^{-1} citric acid is effective in stabilizing soybean oil against flavor and oxidative deterioration.

21–4.5 Hydrogenation

When soybean oil is to be used as a cooking oil or in the formulation of margarines and shortenings, it must be partially hydrogenated to improve high-temperature stability and to physically harden the oil (Allen, 1978). Most hydrogenations are performed as batch processes; however, continuous systems have been patented and are in use (Coombes et al., 1974). Conditions of hydrogenation range from 0.01 to 0.1% Ni catalyst, at 140 to 225°C and at pressures of 0.05 to 0.6 MPa gauge. Soybean oil is generally hydrogenated to an iodine value of 110 to 115 for use as a cooking oil, 80 to 90 for margarine base stock oil, and 60 to 70 for shortenings (Weihrauch et al., 1977).

Partial hydrogenation of edible oils is practiced to increase stability by the selective reduction of linolenic acid. Commercially, a dual purpose salad/cooking oil is prepared by hydrogenation of soybean oil with Ni catalysts under selective conditions, such as 35 to 97 $\times$ 10^3 Pa, 0.05% catalyst at 177°C. The oil is hydrogenated to an iodine value of 110 to 115 and must be winterized to meet the requirements of the standard American Oil Chemists' Society cold test (Link, 1975). This test calls for the oil to remain clear for a minimum of 5.5 h at 0°C. Stearine, high melting glycerides, and palmitic and stearic acid fractions are removed by the winterization process (Numenz, 1978). Oil is chilled slowly to about 6°C during a 24-h period; at this point cooling is stopped and the oil/crystal mixture is allowed to stand for 6 to 8 h. The yield of liquid oil is approximately 75 to 85%. By-product stearine is generally used for shortening manufacture. Mounts et al. (1978) showed that although hydrogenation of soybean oil to linolenic acid contents of 3.3 and 0.4%, gave a significant improvement in the oxidative stability, as measured by the active oxygen method (AOM), it did not give a significant improvement in the flavor stability of the oil during accelerated storage tests up to 8 days at 60°C. The oils in these tests were all treated with citric acid on the cooling side of deodorization. Frankel (1980) attributes the improvement of the oxidative stability of soybean oil to the conversion of linolenic acid into isolinoleic and monoenoic acids, which are more difficult to oxidize. Some of these compounds have double bonds between positions 14 and 16 in the C chain and may produce flavor compounds similar to those of linolenic acid upon oxidation, which may explain why hydrogenation does not have a significant impact on flavor stability during storage. Lowering of the linolenic acid content does provide increased stability during use of soybean oil as a cooking oil. It is still, however, only a partial solution to the problem, and thermal oxidation will eventually produce objectionable odors and flavors.

After deodorization, all soybean oils, whether or not hydrogenated, are subject to oxidation when the oil is in contact with air. Areas of treatment of edible oils with N_2 to ensure proper protection are summarized in Table 21–6.

21–4.6 Energy Conservation

A major concern of the edible oil industry in the 1970s and 1980s has been energy conservation. All of the processing steps just discussed consume energy to heat and cool the oil and to generate the required vacuum levels. The bleaching, deodorization, and hydrogenation steps offer the greatest opportunity for conservation (Gavin, 1983) by means of various energy recovery techniques.

21–5 FOOD USES OF SOYBEAN OIL

21–5.1 Salad and Cooking Oils

As noted earlier, salad and cooking oils constitute the largest volume usage of soybean oil. Partial selective hydrogenation of soybean oil to lower its linolenic acid content to about 3% considerably improves the oil's flavor and oxidative stability. Blending soybean oil with an oil containing little or no linolenic acid is also done to lower the linolenic acid content, i.e., with cottonseed oil (Carpenter et al., 1976). Some dual purpose salad/frying oils contain an antifoam agent, usually a silicone compound (Freeman et al., 1973; Lorenz, 1978).

Soybean oil is the major oil used in mayonnaise and prepared salad dressings. Most mayonnaises contain 77 to 83% oil (Newkirk et al., 1978). A thicker product containing 80 to 84% oil is often used in institutions. While oil is the major component, mayonnaise is an oil-in-water emulsion, that is, the oil is the dispersed rather than the continuous phase. Prepared salad dressings use mayonnaise as the base and include one or more of the following ingredients: minced onions, minced green peppers, chopped stuffed olives, hard-cooked eggs, and chili sauce (Anonymous, 1963). Imitation mayonnaises contain considerably more water than do regular mayonnaises and only 14 to 40% oil. Spoonable salad dressings must contain at least 30% oil. Both these products use a starch paste as a thickener (Newkirk et al., 1978; Weiss, 1983). Most commercial pourable salad dressings contain 55 to 65% oil while low calorie dressings have a low oil content, i.e., 4 to 14% (Watt and Merrill, 1963).

21–5.2 Margarines

Margarine, originally developed as a butter substitute, is recognized as a high-quality, nutritious product available in several forms for table

Table 21–6. Summary of treatment areas with N_2 to protect edible oils.

Area of treatment	Method of introducing N_2	Classification	Approximate usage
Manufacturing-pumping from deodorizer	In-line between cooler and storage tank	Sparging	Approx. 0.025 ft^3/gal (3.7×10^{-4} m^3 L^{-1})
Bulk-oil storage	Nitrogen in-line sparger directly into headspace	Blanketing	Enough to maintain positive pressure
Filling of tank cars	In-line between storage and tank car	Sparging	1000 ft^3 (28 m^3) per 8000–gal (30 240 L) car
Tank car or truck	Into headspace of car after filling	Blanketing	Undetermined
Customer's plant-pumping from tank car to oil storage	Sparging in-line during pumping	Sparging	Approx. 0.025 ft^3/gal (3.7×10^{-4} m^3 L^{-1})
Storage in tanks	Directly into headspace plus N_2 from in-line sparger	Blanketing	Enough to maintain positive pressure
Pumping from storage to filler or header	Sparging in-line during pumping	Sparging	Approx. 0.025 ft^3/gal (3.7×10^{-4} m^3 L^{-1})
Filler bowl or header	Entrance into closed filler bowl or header	Blanketing	Maintain light pressure
Closing or capping machine	Shroud or purge technique	Blanketing or purging	Undetermined

use and is no longer considered a substitute (Massiello, 1978). Regular margarine contains 80% fat and about 16 to 18% aqueous phase. Cow's milk, pure water, or water plus some edible protein, such as nonfat dry milk solids or soybean protein may constitute the aqueous phase (Code of Federal Regulations, 1977a, 1977b). Other ingredients are 2 to 3% salt (except for salt-free margarine); emulsifiers, such as mono- and diglycerides and/or lecithin; preservatives; flavoring; coloring, usually β-carotene; fortifiers, i.e., 15 000 U.S. Pharmacopeia (USP) units of vitamin A and sometimes 2 000 USP units of vitamin D; and optional ingredients such as butter, nutritive sweetners and fat antioxidants.

Until 1955, stick or brick-type margarine was the only table-grade type available. By 1976, this type constituted only 22% of the margarine market and 10 types of margarine and manufactured spreads were available. Currently, products for the consumer retail market are the principal margarine production (Table 21–7).

Basic steps involved in margarine manufacture include: (i) formulating the margarine oil blend, (ii) preparing the aqueous phase, (iii) preparing the emulsion, (iv) solidifying the emulsion and controlling its plasticity, (v) packaging the margarine, and (vi) tempering the packaged margarine, if necessary.

The oil formulation, the manner and degree of super-cooling the emulsion, and the extent of mechanically "working" the supercooled emulsion during the crystallizing stage are all used to control margarine plasticity. If the fat composition is rapidly supercooled and allowed to solidify without agitation, the margarine will become quite firm and have a narrow plastic range. The plastic range is extended by mechanically

Table 21–7. U.S. margarine production, 1985.†

Type of margarine	Quantity	
	10^3 t	%
Consumer retail products		
¼ lb (0.11 kg) Sticks	503.8	
1 lb (0.45 kg) Soft tubs	134.8	
Country patties	10.4	
Solids or rolls	64.4	
Spreads	220.4	
Diet and imitation, all sizes	43.5	
Subtotal	977.3	82.8
Food service products		
1 lb (0.45 kg) Solids or rolls	72.6	
Individual servings	14.9	
Subtotal	87.5	7.4
Bakery and industrial products		
Bulk sizes more than 1 lb (0.45 kg)	96.7	8.2
Total production	1180.6‡	100.0

†National Association of Margarine Manufacturers based on data reported by U.S. Bureau of Census (1986, personal communication.)

‡The sum of margarine packaged by package sizes does not agree with the total production because some margarine is not packaged during the same month in which it is produced.

working the emulsion while the fat is crystallizing from the supercooled state (Wiedermann, 1978). The melting point, fatty acid composition, and structure of the individual triglycerides influence the structural, nutritional and lubricity aspects of the margarine. Stick margarines usually are made from a blend of two or three intermediate fats, or of a low IV fat and a liquid oil. Soft margarines contain a high proportion of liquid oil; fluid margarines have the highest proportion.

The fats and oils selected for the margarine oil blend are mixed in the proper proportions and heated to 38°C (100°F) or more, and the oil-soluble ingredients are added. These additives include emulsifiers, usually mono- and diglycerides and sometimes lecithin, plus specified amounts of vitamins and desired flavoring and coloring ingredients.

The aqueous phase is prepared separately. A milk phase is prepared by adding dried protein such as whey or nonfat dry milk solids to water, then pasteurizing and cooling the mixture. Water-soluble ingredients, usually salt and preservatives, are also added (Wiedermann, 1978).

In the batch-continuous process, the oil and aqueous phases are prepared batch-wise in separate tanks, then the two phases are blended; the resultant emulsion is solidified on a continuous basis, as will be described later. Batch-wise blending of the two phases is done in a premix tank that often is referred to as a churn. Holding time in the churn is kept to a minimum because the temperature (30°C) is ideal for bacterial growth. If automatic proportioning equipment is used, the two phases can be prepared on a continuous rather than batchwise basis if proper temperature control is employed. Most margarine manufacturers in the USA prefer to weigh the major ingredients into the churn (Moustafa, 1979).

The oil and aqueous phases are emulsified to the proper degree as, or just before, the blend enters the first of three heat exchange chilling tubes of the continuous processing unit. Water in the emulsion is dispersed as droplets of about 5-μm diam and then kept from coalescing. Mono- and diglycerides help create and maintain an emulsion containing small droplets (Moustafa, 1979). The emulsion is cooled in a matter of seconds (5–10) by ammonia refrigerant vaporizing in the jackets of the heat exchangers. Scrapers continually remove solidified fat from the inner wall of the heat exchangers (often referred to as the A units) to promote rapid heat transfer. Small crystals form as the emulsion is supercooled (e.g., to 45–50°F or 7–10°C).

For regular (stick type) margarine, the supercooled, still-fluid melt is piped to either of twin crystallizers, referred to as B units. These are enlarged, empty cylinders wherein the emulsion remains stationary (typically, ca. 2 min) until crystal development proceeds to a point where the product is sufficiently firm to withstand the forces applied in extruding, shaping, and wrapping the margarine in high-speed automatic machinery. By use of twin crystallizers, the emulsion can remain stationary in one while the other is being filled. The temperature increases several degrees in the B unit because of the heat of crystallization.

Whipped margarines are produced by incorporating N_2 into the margarine. The gas is introduced ahead of one of the heat exchangers or at the suction side of the feed pump. This type margarine requires vigorous mixing in the B unit (as defined above) to limit the extent of crystal development; otherwise, the margarine becomes too firm. For this process, the B unit is a worker-type crystallizer. It has radial pins on a rotating central shaft, and these pins intermesh with stationary pins protruding from the cylinder wall. The agitation is controlled to allow crystal growth and yet prevent the formation of a firm crystal lattice. The soft, semifluid mass is packaged immediately in specially designed print-forming (i.e., stick-forming) machines that squeeze little or no N from the margarine. The gas increases the margarine's volume by 50% and makes the margarine softer and easier to spread at refrigerator temperatures.

Soft-tub margarines containing as much as 70 to 80% liquid oil are produced by chilling the emulsion in a single A unit and then mixing the chilled mass in a large, agitated crystallizer. Working the chilled emulsion to a limited degree prevents the fat crystals from growing into a firm network. The soft, fluid margarine is packaged in plastic tubs by a liquid-filling machine. Crystal development continues in the tub to give a soft, semisolid product. After packaging, soft tub margarines are tempered by holding 24 h or more at about 7°C (45°F), so that the crystal structure can become fully developed and stabilized (Moustafa, 1979).

21–5.3 Shortenings

Soybean oil constitutes about 64% of the fat used in the manufacture of shortening, while the other major fats (24%) are edible tallow and lard (Anonymous, 1982). Shortenings are used in the preparation of many foods and impart a tender quality to baked goods. In addition, in baked goods, shortenings enhance the aeration of leavened products; add to the flavor; promote a desirable grain and flavor; assist in the development of flakiness in products such as pie crusts, Danish and puffed pastry products; modify the wheat gluten, particularly in the development of yeast-raised doughs; and act as emulsifiers for the retention of liquids (Baldwin et al., 1972). Shortenings perform two chief functions in baked goods: (i) a leavening and creaming action, and (ii) a lubricating function. In icings and fillings, shortenings are used to entrain large volumes of air bubbles and thus produce a fine delicate structure. Large quantities of shortenings are used in the preparation of fried foods both by deep fat and by pan and grill frying. Fats play a dual role by aiding in the transfer of heat to the food being fried and by being partially absorbed by the food, contributing to nutritive value and to flavor.

Prior to 1961, shortenings were formulated from highly hydrogenated oils having substantially reduced polyunsaturated fatty acid (PUFA) contents ranging from 5 to 12%. Since 1961, shortenings have been produced with higher levels of polyunsaturated fatty acids, typically containing 22 to 32% PUFA. This change has been in response to research which suggests that intake of polyunsaturates plays a beneficial role in reducing blood cholesterol levels.

The basic steps in shortening manufacture are: (i) preparation of the individual basestocks and hardfats, (ii) formulation of the fat blend and other ingredients, (iii) solidifying and plasticizing the fat blend, (iv) packaging, and (v) tempering the shortening, when necessary. Tempering generally is limited to the plastic shortenings and margarines used for baking.

Tempering consists of holding the shortening for 24 to 72 h in a room maintained at a constant temperature, usually somewhere between 27 and 32°C (80–90°F). The holding time is determined by factors such as container size and type of shortening. Crystallization continues slowly during the tempering step. Tempering stabilizes the crystal structure against changes that might otherwise occur during subsequent temperature variations encountered in normal handling and storage.

Plastic shortenings generally are solidified and plasticized in scraped surface, heat exchanger equipment similar to that used in the production of whipped or soft margarines described earlier. The melted fat plus optional ingredients are chilled rapidly from 46–49°C (115–120°F) to 16–18°C (60–65°F) in one or more A units to produce numerous nuclei for crystal formation. The supercooled melt then is piped to a worker-type B unit wherein the shortening is agitated as the crystals grow and the mass partially solidifies. From 10 to 20% air or an inert gas is added and dispersed in the shortening as small bubbles. In this form, the air improves the whiteness of the product and sometimes contributes to its creaming ability. The plastic mass is pumped through a homogenizing valve and then to package fillers. The packages vary in size from 0.45-kg (1-lb) tins that are sealed after filling to open-end drums 172-kg (380-lb) having removable covers.

21–5.4 Emulsifiers

Emulsifiers have a number of functions in both plastic and pourable shortenings as well as in other lipid-containing food products. The functions include: stabilizing emulsions as in margarines and salad dressings; antispattering in margarines; texture control in bread and cakes; dough conditioning and antistaling in bread; aerating in cakes, toppings, and icings; plasticizing cake icings; and wetting in coffee whiteners and instant foods. Food emulsifiers probably are used in greater quantities than any other food additive (Nash and Brickman, 1972). A number of factors influence emulsifier selection, including: ingredient formulation, flavor, type of homogenizing and heating equipment, product preparation technique, finished product form (e.g., liquid, powder, and plastic solid), storage requirements, costs, and legal aspects.

There now are seven, legally sanctioned emulsifiers that are widely used in yeast-raised bakery products. Each is fat-derived, and they include (Landfried, 1977): (i) mono- and diglycerides (40–50% content), (ii) distilled monoglycerides (90%), (iii) succinylated monoglycerides, (iv) ethoxylated mono- and diglycerides, (v) Polysorbate 60, (vi) calcium stearoyl-2-lactylate, and (vii) sodium stearoyl-2-lactylate. Several of the above, as well as others, are used in cakes and other chemically leavened baked goods. The mono- and diglyceride-type emulsifiers will vary in hardness with the degree to which the fatty acid portion has been hydrogenated.

21–5.5 Nutritional Considerations

The disappearance of visible animal and vegetable oils and fats in the USA was estimated at 5.8 Tg for 1984. Based on 1980 USDA statistical data, Rizek et al. (1983) have estimated average total fat consumption at 13.5 Tg or 169 g (0.37 lb.) per person per day for 1980. However, actual consumption is considered to be about 23% (40 g) less due to waste and/or losses. As shown in Table 21–8, of the 169 g of total edible fat consumed, 72 g (42.6%), was visible fat. About 13.3% of the visible fat is estimated to be supplied by unhydrogenated soybean oil (SBO) and 39.6% by hydrogenated soybean (HSBO) plus small amounts of other hydrogenated vegetable oils such as corn (*Zea mays* L.), peanut, (*Arachis hypogaea* L.), cotton (*Arachis hypogaea* L.), and sunflower (*Helianthus annuus* L.) (Table 21–8).

Since hydrogenated soybean oil alone contributes more than 23% of the total fat intake and about 10% of the total calorie intake, questions have been raised concerning its nutritional value. However, these concerns do not involve the actual hydrogenation reaction that converts alkene bonds in unsaturated fatty acids to saturated or alkane bonds. The questions are instead based on the isomerization reaction, which is a secondary or side reaction that occurs during hydrogenation and is the reaction which produces the new fatty acid structures or isomers that are not present in unhydrogenated SBO. As a result, a variety of mono- and polyunsaturated isomers are formed which consists of both *cis* and *trans* positional isomers. Metabolic and other studies have shown that, with minor differences, monounsaturated *trans* fatty acids are metabolized and utilized similar to the corresponding *cis* acids. Numerous studies in which high levels of *trans* fatty acids were fed to animals for long periods of time with adequate dietary essential fatty acids, have shown no adverse effects. These studies as well as others with humans have been reviewed recently by Emken (1985). Recent studies (Ohlrogge et al., 1982) have indicated that monounsaturated positional and geometric isomers in partially hydrogenated soybean oils are metabolized and do not accumulate abnormally in lipids extracted from human tissues.

21–5.6 Lecithin

An important by-product of soybean oil processing is lecithin which is obtained during the degumming of the oil. The sludge which is obtained from the degumming centrifuges contains about 40 to 50% water. The sludge is dried to a moisture content of about 1% in continuous, agitated-

Table 21-8. Dietary sources of energy for the U.S. population (Emken, 1985.)

Energy Source	Total calories	Daily per capita fat consumption					
		Visible		Nonvisible		Total	
	%	g	%	g	%	g	%
Butter and animal	24.5	21.2	29.4	77.4	79.8	98.6	58.3
Soybean oil	3.3	9.6	13.3	3.7	3.8	13.3	7.9
Hydrogenated oil	9.8	28.5	39.6	11.0	11.8	39.5	23.4
Vegetable oils (other)†	4.4	12.7	17.7	4.9	5.1	17.6	10.4
Total fat	42.0	72.0	42.6	97.0	57.4	169	100
Total carbohydrate	46.0						
Total protein	12.0						

†Includes corn, peanut, cottonseed, and sunflower oils.

film evaporators, operating on either a vertical or horizontal axis. The horizontal axis type is preferred since the tendency for the lecithin film to break is reduced (Van Nieuwenhuyzen, 1976). The commercial soybean lecithin produced contains about 35% soybean oil and 65% phosphatides, carbohydrates, and moisture (Brekke, 1980). While trading rules specify only six grades of lecithin (NSPA, 1984–1985), a more definitive classification of lecithin types has been proposed as outlined in Table 21–9 (Flider, 1985). For a detailed discussion of the manufacture of these types the reader is referred to the recent monograph *Lecithins* (Szuhaj and List, 1985). Lecithins are used in many food applications in which advantage is taken of their surface-active effects. Lecithin products have both a lipophilic and a hydrophilic group in the same molecule and therefore act at the boundary between immiscible materials (Szuhaj, 1980). The major functions of lecithin in food uses are in collodial dispersion, wetting, lubrication and release, crystallization control and starch complexing. These same functions find application in nonfood uses such as coatings manufacture and finishing, glass and ceramics processing, and metal processing.

21–6 NONFOOD USES OF SOYBEAN OIL

Because of its low cost and availability, soybean oil is the most important vegetable oil used for industrial products. In 1983, 5.8% of the 4.5 million t of soybean oil used in the USA was applied to industrial purposes (USDA, 1984c). The overall consumption of fats and oils in inedible products has declined in recent years as shown in Table 21–10.

Table 21-9. Lecithin types (Flider, 1985).

- I. Natural
  - A. Plastic
    1. Unbleached
    2. Single-bleached
    3. Double-bleached
  - B. Fluid
    1. Unbleached
    2. Single-bleached
    3. Double-bleached
- II. Refined
  - A. Custom-blended natural
  - B. Oil-free phosphatides
    1. As is
    2. Custom-blended
  - C. Fractionated oil-free phosphatides
    1. Alcohol-soluble
       - a. As is
       - b. Custom-blended
    2. Alcohol-insoluble
       - a. As is
       - b. Custom-blended
- III. Modified chemically

Table 21–10. Nonfood (industrial) consumption of fats and oils

Inedible products	1978†	1983‡
	10^3 t	
Soap	396	368
Paint and varnish	114	66
Fatty acids	1 035	844
Feed	630	670
Resins and plastics	62	82
Lubricants	75	42
Other	333	277
Total	2 645	2 349

†Bureau of the Census (1979).
‡USDA (1984c).

Use of soybean oil for inedible products, however, has grown by 13% since 1976 to a total of 260 000 t in 1983. The primary markets for soybean oil are in alkyd paints and in an epoxidized derivative as a plasticizer/stabilizer for vinyl plastics (Pryde, 1983). Modified soy fatty acids and amines have found application as surfactants and antierosion agents; brominated soybean oil is added to fruit-based soft drinks to improve cloud stability and reduce ring deposits. Soapstock, a soybean oil processing by-product, is used as a feed additive and as a chemical feedstock in the fatty acid industry. New products from soybean and other vegetable oils and new applications have been the object of research in the areas described below.

21–6.1 Coatings and Plastics

High-solids and water-dispersible coatings have been developed. Derivatization of soybean oil by treatment with ozone yielded high solid resins suitable for baked coatings on metal surfaces (Thomas and Gast, 1979). Water-dispersible resins, containing 70 to 80% vegetable oil-derived material and 20 to 30% of petrochemical-derived materials gave films which dried rapidly at room temperatures to form flexible, adherent coatings (Schneider and Gast, 1978, 1979).

Engineering thermoplastics are exemplified by those nylons that are cast and formed into gears, gear housing, and the like. One experimental type of nylon can be made from soybean oil which absorbs less moisture than nylon used for clothing and, consequently, has better dimensional stability and dielectric properties in moist environments (Perkins et al., 1975).

21–6.2 Lubricants

Building blocks used in the petrochemical industry, such as synthesis gas (a mixture of carbon monoxide and hydrogen), can be used with vegetable oils to make lubricants. One such derivative made from soybean oil could be used at extraordinarily low temperatures (to almost

−70°C or −90°F) (Dufek et al., 1974). Other derivatives of soybean oil were prepared that could serve as substitutes for sperm whale oil and as lubricants for continuous casting of steel (Bell et al., 1977). Investigations on the sulfurization of soybean oil have given some important leads to the development of high-pressure lubricant additives for use in automative automatic transmission fluids (Schwab et al., 1978).

21–6.3 Diesel Fuels

Vegetable oils for diesel fuel have a number of advantages. They are liquid fuels from renewable resources and have a favorable energy input/output ratio, unless produced on irrigated land. They would permit crop production even in a petroleum shut-off and have potential for making marginal lands productive. They consume less energy than does alcohol production and have higher energy content than alcohol. They have cleaner emissions and simpler technology than alcohol production. One disadvantage is that vegetable oils for diesel fuels as yet are not economically feasible. Further research and development are needed.

In comparing the properties of soybean oil with diesel oil as shown below, it can be noted that the cetane number and the heat content are similar.

Property	No. 2 diesel oil	Soybean oil
Density, kg L^{-1}	0.852	0.925
Cetane number	49	37
Heat content, 10^6 J kg^{-1}	42.4	39.1
Viscosity, CTS at 100°F	1.9–4.1	36
Volatility		
°C	220–355	nonvolatile
°F	430–675	nonvolatile
Flash point		
°C	> 52	300
°F	> 125	570

However, soybean oil is far more viscous than diesel oil and has low volatility. Research has shown that vegetable oils can be used successfully in a naturally aspirated, air-cooled, *indirect*-injection diesel engine; they cannot be used neat in *direct*-injection engines. Since the great majority of farm tractors in the USA have direct-injection engines for greater fuel efficiency, some kind of modification to vegetable oils appears to be necessary before they can be used in this type of equipment.

Scientists at Purdue University have tested blends of reclaimed cooking oil with diesel oil in campus buses with direct injection engines (Engelman et al., 1978). The optimum blend was 20% in diesel oil which gave the lowest smoke emission and fuel consumption at full load. The incorporation of aqueous ethanol into vegetable oil to form a microemulsion serves not only to extend diesel fuel supplies but possibly also to improve combustion properties. Vegetable oils, when injected into the combustion chamber of a diesel engine cylinder, do not form the atomized spray typical of no. 2 diesel oil. As a consequence, combustion is incomplete, and injector coking, ring sticking, and lubricant contamination are major problems. It is hoped that the microemulsions will form a better spray pattern and give superior engine performance because of the lower viscosities of the microemulsions compared to the original oil. Vegetable oil esters, formed by the transesterfication reaction with simple alcohols, are also being evaluated for fuel use. For a more complete update on this area, see the proceedings of a recent conference on this topic (USDA, 1983).

21–6.4 Ag-Chem Uses

Interest in using soybean oil as carriers for pesticides or as spray adjuvants has resulted in extensive research to develop formulations, to define application and dispersal equipment, and to evaluate the efficiency of the new formulations in field trials. For a complete review of current research in this area see the Proceedings of the Ag-Chem Uses of Soybean Oil Workshop (American Soybean Association, 1984). Pesticides must be applied as liquid sprays in most cases. The most extensively used carrier to dissolve or disperse the solid or viscous organic pesticides has been a special phytobland grade of mineral oil. Soybean oil is a less expensive alternative for this purpose. Research has been directed to confirm that soybean oil fulfills the requirements for use as a solvent or carrier, i.e., the agricultural chemical must be soluble or dispersable, and it must be phytobland or nonphytotoxic. With normal application rates the oil/pesticide solution is diluted with water with an added surfactant or emulsifier. Through use of ultra-low volume (ULV) application systems, oil-soluble pesticides can be applied directly without further dilution with water. As a spray adjuvant, soybean oil is a competitive alternative to mineral oil for addition to water-based solutions, emulsions or suspensions of herbicides to alter the spray characteristics. Adjuvants provide adhesive effects for dry residues remaining from particulate sprays or reduce the surface tension of the spray droplets, which causes them to readily spread over the surface of the plant. Tests have demonstrated that soybean oil is a viable alternative to mineral oil in these applications in that most pesticides are sufficiently soluble or dispersible for use; soybean oil is less volatile and improves droplet stability important to control of wind drift in ULV applications; and soybean oil is not phytotoxic to plants.

Another significant potential market for soybean oil is its use as a dust suppressant in grain handling. Recent research (Lai et al., 1981) has demonstrated that dust concentration during handling is reduced by more than 90% by application of soybean oil to wheat and corn at a rate of 0.03%. The dust suppressant effect was retained throughout the 1-yr period of the test. Considerable testing is required before this technique of dust suppressant is adopted including determination of threshold limits of odor detection of soybean oil and combinations of oil and lecithin, final determination of optimum treatment levels, assessing the quality of end products from treated grain, and effect of oil treatment on handling machinery.

21-7 DEFATTED SOYBEAN PROTEIN PROCESSING

21-7.1 Toasting for Feed Use

The bulk of defatted meal produced in the USA is used in animal feeds. Meal intended for feeds is prepared by processing hexane-laden flakes coming from the extractor in conventional D-T units (Fig. 21-1). Such units consist of several compartmentalized stages in which the flakes are agitated and moved downward through each stage. In the first stages, the hexane is stripped out by injecting live steam which condenses and raises the moisture content to about 20%. In later stages, the flakes are toasted and partially dried. After leaving the D-T unit, the flakes go to a drier where moisture content is reduced to 10 to 12%. Flakes from the drier, after cooling, are ground in a hammer or other type mill, screened to the desired grit size and stored as finished meal. An alternative to the conventional DT is the desolventizer-toaster dryer cooler (D-TDC) where the entire operation is carried out in one piece of equipment (Lebrun et al., 1985). The D-TDC consists of four stages: (i) predesolventizing; (ii) desolventizing-toasting; (iii) drying; and (iv) cooling.

Toasting is necessary to obtain optimal growth when soy meal is fed to animals. Enhancement of growth by toasting is caused by inactivation of a number of antinutritional factors including trypsin inhibitors and hemagglutinins plus denaturation of the storage proteins to make them more digestible (Liener, 1981). The antinutritional factors are discussed later (section 21-8).

21-7.2 Conversion into Edible Products

In the USA, edible soybean proteins fall into three major classes: (i) flours and grits; (ii) concentrates; and (iii) isolates. All three types are made from defatted soybean flakes which are prepared by hexane extraction essentially as described earlier (section 21-3) except that greater attention is paid to sanitation, and desolventization is performed in a flash desolventizer or vapor desolventizer-deodorizer instead of a D-T unit (Becker, 1978; Mustakas et al., 1980). Both desolventizing processes use superheated hexane to flash evaporate the hexane from the flakes with a minimum of protein denaturation which is desirable if the flakes are intended for preparation of isolates. If toasted or partially toasted, defatted flakes are required, the toasting operation is carried out in a flake stripper-cooker or deodorizer (Milligan and Suriano, 1974; Becker, 1978).

This operation also removes residual hexane and volatile flavor components.

21-7.2.1 Flours and Grits

These products containing a minimum of 50% protein are made by grinding and sifting defatted flakes. Grits are coarse-ground flakes and are graded according to particle size. Flours are ground finer than grits and standards for flours require that 97% of the product passes through a No. 100 mesh screen. Flours with smaller particle sizes are also available.

21-7.2.2 Protein Concentrates

Concentrates are defined as products containing a minimum of 70% protein on a dry basis. They are manufactured from defatted flakes or flours by extracting with aqueous ethanol (Mustakas et al., 1962) or with a dilute acid at pH 4.5 (Sair, 1959) to remove soluble sugars (sucrose, raffinose, and stachyose) and minor constituents. The acid-leached concentrate is neutralized before spray drying to make the proteins more soluble in food systems. The alcohol process is most widely used. Yields of concentrates are 60 to 70% of the weight of starting flakes or flour. Removal of raffinose and stachyose is preferred for some food applications because these oligosaccharides are not hydrolyzed and absorbed but rather pass intact into the lower digestive tract where they are fermented to produce flatus (Rackis, 1981).

21-7.2.3 Isolates

These are the most highly refined class of soybean proteins available and contain a minimum of 90% protein on a moisture-free basis. Defatted flakes prepared with a minimum of heat treatment are extracted with dilute alkali (pH < 9) and centrifuged. The extract is then adjusted to pH 4.5 to precipitate the proteins. The resulting protein curd is recovered by centrifuging, washed, and then usually neutralized with food grade alkali before spray drying to yield the proteinate form of isolate. Unneutralized (isoelectric type) isolates are also available but are less frequently used because of their insolubility. Yields of isolates are about 30% of the weight of the starting flakes or about 60% of the protein in the flakes. Because of the lower yields and the cost of processing, isolates are more expensive than flours or concentrates.

21-7.2.4 Textured Protein Products

Flours, concentrates, and isolates are also processed to give them meat-like textures. Flours and concentrates are textured by thermoplastic extrusion (Harper, 1978). The flours or concentrates are mixed with water and additives to form a dough, which is then fed into an extruder where the dough is subjected to high temperatures, pressure, and mechanical stresses. The dough is squeezed through a die that puffs it and gives it a fibrous texture similar to certain meat products. Bits, ribbons, or sheets of products can be obtained by using an appropriate die in the extruder.

Textured isolates can be made by a spinning process analogous to spinning textile fibers. Isolate is dissolved in sodium hydroxide (pH 10–11) to form a spinning dope which is then pumped through a spinnerette into a coagulating bath containing acid and salts. The protein coagulates to form continuous filaments which are gathered into bundles or "tows". The tows are then washed, stretched, blended with fats, colors, flavors, and other additives for fabrication into a variety of sizes and shapes resembling meat products, such as chicken, beef, bacon, and seafood (Thulin and Kuramoto, 1967). Several companies in the USA and Europe have used the spinning process in the past, but only two American companies are spinning fibers at present. The process is complex and expensive and the meat analogs have not been widely accepted by consumers.

An alternative to spinning is the use of jet cooking to form fibers (Hoer, 1972). A slurry of isolate is pumped through a heat exchanger under high pressure at 116 to 157°C and expelled through a slot-like or small circular nozzle. The isolate is coagulated by the high temperature to form fibers which are dropped through ambient air for cooling, collected in a vessel, and finally centrifuged to remove excess water. The fibrous isolate is sold frozen.

21–7.3 Product Range and Composition

The protein products derived from soybean are available with a range of characteristics depending upon intended use.

21–7.3.1 Feed Products

Defatted soybean meal used for feeds is available in two forms—with hulls and dehulled—that differ primarily in protein and crude fiber contents. Table 21–11 shows compositions of the two types of meal plus edible grade protein products; typical data for soybean are included for comparative purposes. Meal containing 44% protein is processed by omit-

Table 21–11. Composition of soybean, defatted soybean meals, flours, concentrates, and isolates.

Product	Moisture	Protein	Fat	Fiber	Ash
			%		
Soybean†	11.0	37.9	17.8	4.7	4.5
Defatted meal, with hulls‡	10.4	44.0	0.5	7.0	6.0
Defated meal, dehulled‡	10.7	47.5	0.5	3.5	6.0
Full-fat soy flour†	5.0	44.3	21.0	2.0	4.9
Defatted grits and soy flour†	7.0	54.9	0.8	2.4	6.0
Lecithinated soy flour†	5.5	49.9	15.5	2.1	5.0
Protein concentrate†	7.5	66.6	—	3.5	5.5
Protein isolate†	5.0	93.1	—	0.2	4.0

†Smith and Circle (1972). ‡Allen (1984).

ting the dehulling step or by dehulling, grinding the hulls, and then adding them back to the meal after the oil has been extracted. The presence of the hulls decreases the protein content and increases the fiber content. Dehulled meal contains 47.5% minimum protein and only 3.5% fiber.

21-7.3.2 Edible Products

Defatted flours and grits are identical in composition (Table 21-11) but differ in particle size. Grits are available in three particle sizes as measured with U.S. Standard Screens: coarse (No. 10-20 screen); medium (No. 20-40 screen); and fine (No. 40-80 screen). Flours are likewise available in various particle sizes; most flours are 100 mesh, but 200 mesh flours are also manufactured. In addition to differences in particle sizes, grits and flours are also available with varying heat treatments ranging from raw (minimum of moist heat treatment) to fully cooked or toasted. Cooking is used to remove the grassy-beany flavor of raw soybean flakes, to alter functional properties such as protein solubility and water absorption and to improve nutritional value.

Concentrates are available in two basic forms depending on the method of preparation as outlined earlier. Concentrates prepared by alcohol extraction have a lower content of water-soluble protein than those obtained by the dilute acid leach process because alcohol causes extensive denaturation and insolubilization of the proteins. The insoluble cell wall polysaccharides make up most of the nonprotein constituents not accounted for in Table 21-1.

Isolates are available in two basic types as described earlier: (i) isoelectric isolates and (ii) proteinates. Two U.S. manufacturers also provide proteinates with a range of functional properties including gelation, emulsification, water binding, and combatability with acidic foods. Enzymatic hydrolysates of isolates are prepared commercially and are used primarily as whipping agents in confectionary items (Gunther, 1979).

As discussed earlier, flours, concentrates, and isolates are also available in textured forms that have compositions essentially the same as those of the untextured forms (Table 21-11).

21-7.4 By-products

Hulls are a major by-product obtained in the preparation of dehulled, defatted soybean flakes used for 47.5% protein meal and for edible protein products. Hulls constitute 7 to 8% of the soybean and are of low nutritional value because of their high fiber content. They are used mainly in ruminant feeds and find some specialty applications such as vitamin carriers in feeds.

Processing of defatted flakes into concentrates yields by-products consisting of the materials extractable with aqueous ethanol or dilute acid. The major extractables are the sugars, sucrose, raffinose, and stachyose. Some proteins are also extracted, especially by the dilute acid extraction process. The solubles are either discarded or, in the case of the alcohol process, concentrated in the recovery of the alcohol. The recovered soluble sugars are concentrated into a molasses-like syrup (referred to as condensed soybean solubles when concentrated to 60% solids) or dried. The solubles are used as an additive in feeds; feeding studies with rats (*Rattus* spp.) and pigs (*Sus scrofra domesticus*) have been reported (Cline et al., 1976).

Manufacture of isolates yields two by-products: (i) the spent flakes remaining after extraction of the proteins and (ii) the pH 4.5 solubles (also referred to as whey) remaining after precipitation of the proteins at pH 4.5. The spent flakes are disposed of by incorporation into feeds. The whey is discarded or, as practiced by a Brazilian company, sprayed onto soybean flakes before they are desolventized in a D-T unit, thereby incorporating them into soybean meal used for feed.

21–8 UTILIZATION OF DEFATTED SOYBEAN PROTEIN PRODUCTS

As pointed out in the "Introduction," defatted soybean meal is used primarily for feeds. Only small amounts of defatted soybeans are processed further into edible grade proteins (Table 21–5) that are utilized as ingredients in a variety of food products.

21–8.1 Feed Uses

Because of its high nutritional value, wide availability, low cost and consistency of composition, soybean meal has displaced most of the animal proteins (meat meal, tankage, and fish meal) and has become a vital component of poultry and swine feeds in the USA and Canada. Extent of useage of soybean meal is affected by its price relative to that of other oilseed meals. Uniformity in composition is supported by analyses of 21 413 dehulled soybean meal samples in 1976 to 1982. The yearly means of protein content (on an as-is basis) varied only from 48.50 to 49.31% (Jones, 1984).

For 1984, it was estimated that the amounts of oilseed meals fed in processed feeds in the USA would be as follows (USDA, 1984b):

Meal	Tg	Percent
Soybean	16.2	90
Cottonseed	1.4	8
Sunflower	0.4	2
Linseed	0.1	—
Total	18.1	100

Soybean meal is clearly the dominant oilseed meal available as a high protein ingredient for animal feeding in the USA. In contrast, the amount of animal proteins (tankage and meat meals, fish meals, and milk products) available for feeding was only 1.8 Tg or 10% of the quantity of oilseed meals.

Meals available for livestock and poultry feeding and their specifications as set by the National Soybean Processors' Association are compared with the approximate composition of soybean and their seed parts in Table 21–12. The 44% protein meal contains the hulls and is therefore high in fiber; its use is primarily for older pig rations and for cattle feeding. Dehulled meal (47.5–49.0% protein) contains only 3.3 to 3.5% fiber and is mainly utilized in poultry feeds, especially in broiler rations. Mill feed, containing 13% protein, consists of hulls removed by air aspiration of undehulled soybean flakes after hexane extraction; it contains some soybean meal and flour. Soybean mill run contains only 11% protein and consists of soybean hulls plus such meal as adheres to them when they are separated from full-fat flakes prior to the hexane extraction process. Because of their high fiber contents, mill feed and mill run are fed mainly to ruminants.

21–8.1.1 Poultry

It is estimated that about 25% of the poultry diets fed in the USA consists of defatted soybean meal (McNaughton, 1981). Composition of a practical chicken (*Gallus gallus domesticus*) starter ration containing 21% protein is shown in Table 21–13. This ration contains 29% of dehulled, extracted soybean meal which supplies 68% of the total protein. Dehulled soybean meal is preferred for poultry rations because it is lower in crude fiber and higher in metabolizable energy than undehulled meal and the other oilseed meals commonly used in feeds. Cottonseed and peanut meals generally are used in poultry rations only if their price per unit of protein is significantly lower than soybean meal. Methionine is the first limiting amino acid of soybean meal when it is fed to poultry,

Table 21–12. Approximate composition of soybean, seed parts, and meal products.†

Component	Protein	Fat	Carbohydrate	Ash
			%	
Whole beans	40	21	34	4.9
Cotyledon	43	23	29	5.0
Hull	8	1	86	4.3
Hypocotyl	41	11	43	4.4
Meal products	Min.	Min.	Max. (fiber)	
Flakes and meal (undehulled, extracted)	44	0.5	7.0	
Flakes and meal (dehulled, extracted)	47.5–49.0	0.5	3.3–3.5	
Mill feed‡	13		32	
Mill run‡	11		35	

†Data for soybean and soybean parts from Kawamura (1967) on a dry basis. Data for meal products from NSPA (1984–1985) on a 12% moisture basis.
‡Typical analysis on a 13% moisture basis.

Table 21-13. Composition of practical chicken starter rations. Data from Powell and Gehle (1976).

Ingredient	Content
	%
Yellow corn	57.25
Soybean meal (49% protein)	29.00
Fish solubles	0.65
Wheat middlings	2.50
Delactosed whey	1.50
Coastal bermudagrass, dehydrated	5.00
Minerals	3.50
Vitamins	0.25
Animal fat	0.25
DL-Methionine	0.10
Choline chloride	0.10

hence synthetic methionine is often added to starter rations. The need for protein in chicken rations decreases as the birds mature, but soybean meal is still the primary protein source used in rations for finishing broilers and for laying hens.

Soybean meal proteins are highly digestible by chickens. A recent collaborative study (Engster et al., 1985) performed with roosters indicated a protein digestibility of 92.0% for soybean meal which was comparable to corn (94.0%) but higher than for a meat meal (88.0%) or wheat middlings (89.0%).

Turkey (*Meleagris gallopavo*) rations are also a substantial outlet for soybean meal; about 18% of the 7.2 Tg of soybean meal estimated to be used in 1984 for poultry was expected to be fed to turkeys (USDA, 1984b). Starter rations for turkeys require more protein than chick starters, consequently higher soybean meal levels are used in turkey starters than in chick starters. Diets recommended for turkey poults 0 to 4 weeks old call for protein contents of 28% (1200 Kcal/lb of diet) to 32% (1400 Kcal/lb of diet); for finishing rations the protein content is reduced to 13.0 to 15.5% of the diet (Scott, 1984).

21-8.1.2 Swine

Because of its excellent amino acid profile, dependable supply and competitive price, soybean meal is the major source of supplemental protein used in swine diets. For 1984, predicted useage of soybean meal for swine feeding was 4.4 Tg (USDA, 1984b).

Like poultry, swine require high levels of protein in their diets and the major amino acids of concern for swine feeding are lysine, methionine plus cystine, and tryptophan. Protein levels recommended for various production stages are as follows (Jensen, 1984):

Production Stage	Percentage protein in diet
Starter, 10-30 lb	20
Grower, 30-120 lb	16

(continued on next page)

Continued.

Production Stage	Percentage protein in diet
Finisher, 120 lb to market wt	14
Breeder	
Gestation	12
Lactation	14

Typically, corn-soybean meal blends are used to provide these protein contents. Beneficial effects of moist heating on soybean meal used for feeding swine have long been recognized. Commercially processed meals give N and amino acid digestibilities (Rudolph et al., 1983) that are comparable to optimal responses obtained with experimentally heated meals (Vandergrift et al., 1983).

Although not ruminants, growing swine apparently can tolerate wide ranges of crude fiber in the diet. Addition of 6% soybean hulls to a corn-dehulled soybean meal diet gave an increase in daily gain without an increase in feed per gain (Kornegay, 1978). Typical swine diets include 23% (preweaner diet) to 7% (finisher) of undehulled soybean meal (Sievert, 1972).

21-8.1.3 Cattle

Because of rising prices of milk proteins since 1975, there has been an increased interest in the use of soybean proteins in calf (*Bos* spp.) milk replacers. There is ample literature indicating that use of defatted soy flour in milk replacers results in poor performance of calves (see review by Barr, 1981). The causes for poor performance with defatted soy flour are not clearly established but factors such as poor digestibility of nutrients, presence of trypsin inhibitors, and antigenicity have been proposed as responsible. A variety of chemical treatments of soy flour have been evaluated to improve soy flour for use in calf starters. Alcohol extraction or merely contacting with alcohol is reported beneficial and one U.S. company sells a calf milk replacer that contains alcohol-treated soy flour as a partial replacer for milk protein. Barr (1981) estimated that about 70% of the dairy herd replacement calves are fed milk replacers and that 60 to 65% of the replacers contain some soy proteins. About three to five million calves were believed to consume milk replacers containing chemically processed soy flour or soybean protein concentrate. Most of these products have 50% or less of the milk proteins replaced by soy proteins.

Soybean meal is, however, an excellent protein source for more mature cattle. Total useage of soybean meal in 1984 was estimated to be 3.6 Tg with about an equal distribution between dairy and beef cattle (USDA, 1984b). For ruminant feeding, soybean meal must compete with urea, by-product meals and high-fiber oilseed meals (cottonseed, peanut, and sunflower meals).

A variety of treatments including heat and addition of formaldehyde and tannins have been applied to soybean meal and other protein sources to make the proteins more resistant to degradation in the rumen but available for digestion in the small intestine (Broderick, 1975). For example, 0.3% formaldehyde substantially reduced ruminal degradation of soybean meal proteins but had little effect on apparent digestibility of crude protein in steers. Higher formaldehyde levels provided little additional protection against ruminal protein degradation but lowered digestibility of the protein, presumably because of excessive cross-linking of the proteins (Spears et al., 1985). If commercialized, the production of protected proteins could provide additional outlets for soybean meal because it has a good balance of essential amino acids.

21-8.2 Food Uses

Edible soybean proteins are used primarily as ingredients in a variety of processed foods (Table 21-14). Defatted flours are the least expensive form of soybean proteins and level of useage varies from 1 to 2% (as functional ingredient such as moisture retainer) to nearly 100% (meat analogs where oil, salt, flavors, and colors are only other ingredients). Protein concentrates sell for three to four times as much as flours but have the advantage of being low in raffinose and stachyose which are largely removed during processing. These oligosaccharides are believed to cause flatulence. Isolates are the most expensive and inefficient form of soybean proteins to use (only 60 to 70% of the protein in defatted soybean flakes is recovered in the production of isolates). An important

Table 21-14. Food uses of soybean proteins.

Protein form	Uses
Defatted flours and grits	Baked goods (breads, crackers, and sweet goods) Ground meat extenders Meat analogs Nonfat dry milk replacers Breakfast cereals Infant foods Diet foods Soup mixes Confections
Concentrates	Processed meats Frozen meat dinners Breakfast foods Infant foods
Isolates	Whole milk replacers Coffee whiteners Cake mixes Beverage products Confections Processed meats Meat analogs Infant formulas

use is in formulas for infants that are allergic to cow's milk; in this application they may be the sole source of protein during the 1st months of life.

Edible grades of soybean protein, especially defatted flour, are generally less expensive than animal proteins but they are less widely used than those of animal origin because of limitations in nutritional and functional properties. Current status of these problems is discussed here.

21–8.2.1 Nutrient-Antinutrient Properties

It has been known since 1917 that soybean meal needs to be cooked in order to support normal growth of rats (Osborne and Mendel, 1917). Numerous studies have been conducted to identify the factor(s) responsible for the poor growth-promoting activity of raw soybean or meal (Liener, 1981). Several heat-liable, as well as heat-stable, antinutrients are now known to occur in soybean.

The most extensively studied heat-labile antinutritional factors in raw soybean meal are the trypsin inhibitors. They cause hypertrophy of the pancreas and increase secretion of enzymes by this organ. The enzymes secreted by the hyperactive pancreas are rich in methionine and cystine, but the enzymes are excreted in the feces, hence there is loss of these S-containing amino acids to the animal. Because S amino acids are first limiting in soybean proteins, their loss in the feces has been postulated to be responsible for the poor growth of rats when they are fed raw soybean meal (Lyman, 1957). The trypsin inhibitors account for about 40% of the growth inhibition of raw soybean plants. Poor digestibility of the undenatured proteins is believed to account for much of the remaining growth inhibition of raw soybean (Kakade et al., 1973).

Recent studies showed that continuous ingestion of soy flour with varying levels of trypsin inhibitor activity results in the formation of pancreatic lesions (McGuinness et al., 1980; Liener et al., 1985). At 6 months, hypertrophy (enlargement caused by increased cell size) and hyperplasia (enlargement caused by increased number of cells) were noted and gross inspection of the pancreas revealed nodules after 15 months of exposure to the trypsin inhibitors (Liener et al., 1985). Detailed histological examination of the pancreas indicated nodular hyperplasia at 6 months of feeding. There was a positive relationship between incidence of the lesion and both time of exposure and level of dietary trypsin inhibitor. After 18 months of ingesting the inhibitor-containing diets, acinar adenoma was observed; adenoma was most prevalent in rats consuming the highest level of trypsin inhibitor in the soy flour diets (Liener et al., 1985). In a related study, protein isolates as well as soy flours were fed for 2 yrs and histological changes in the pancreas were evaluated. Nodular hyperplasia and acinar adenoma were the major pathological changes noted in the pancreas and the development of the lesions appeared to be related only to the level of trypsin inhibitor irrespective of the source (Gumbmann et al., 1985).

The significance of these effects on the pancreas in rats in relation to practical feed rations and human consumption of soybean foods is unknown. It must be remembered that soybean products are always used in foods which are ultimately baked or cooked before eating. These final preparation steps probably significantly reduce the antinutritional factors. Trypsin inhibitors, also, are not unique to soybeans; they occur in many foods that are staples in Western diets. The British diet is estimated to contribute about 330 mg of trypsin inhibitor activity per person per day. Eggs (28%), milk (17%), and potatoes (13%) (*Solanum tuberosum* L.) contribute almost 60% of the total trypsin inhibitor intake (Doell et al., 1981).

Other heat-labile antinutrients in soybean are lectins (hemagglutinins), goitrogens, and antivitamins (Liener, 1981). Lectins are readily inactivated by moist heat and do not appear to have major effects on the nutritional quality of soybean proteins (Turner and Liener, 1975). The effects of the goitrogens in soybean are relatively weak and can be overcome by adding potassium iodide to the diet; they can also be partially eliminated by heat (Block et al., 1961). The antivitamins are likewise inactivated by heat treatment and their effects can be counteracted by supplementation with vitamins and minerals (Liener, 1981).

Heat-stable factors affecting nutritional quality of soybean protein products include phytates, flatulence factors, and allergens (Liener, 1981). Phytates occur in soybean meal at a level of about 1.5% and have long been implicated in interfering with bioavailability of minerals such as Ca, Mg, and Zn (Cheryan, 1980; Erdman, 1979). Recent studies with humans confirmed earlier reports with laboratory animals. For example, addition of sodium phytate to a basal diet containing egg albumin as the protein source decreased dietary Zn absorption in young men from 34 to 18% (Turnlund et al., 1984). Likewise, addition of phytate to a cow's milk-based infant formula (phytate concentration similar to that of soy-based formula) reduced Zn absorption in adult men from 32 to 16% as compared to 14% absorption for a soy isolate-based formula (Lonnerdal et al., 1984). A soy flour-based formula gave a Zn absorption of only 8%. Phytic acid in soybean flakes is hydrolyzed only slowly by autoclaving and hence is stable to moist heat during processing of soybean into oil and meal. Mineral supplementation is, therefore, used to counteract the low absorption caused by phytate.

Flatulence caused by ingestion of soybean products is attributed mainly to raffinose and stachyose and is a problem only with full-fat and defatted flours (Steggerda et al., 1966; Rackis, 1981). Processing of defatted flakes into concentrates and isolates removes the oligosaccharides and eliminates flatulence. Tofu does not cause flatulence and fermentation procedures such as preparation of tempeh also reduce the flatulence activity of soybean (Calloway et al., 1971).

Allergic responses to ingestion of soybean protein by humans are comparatively rare. The medical literature documents occasional cases of allergy to soybean dust in workers in soybean processing plants or food plants using soy flour (Bush and Cohen, 1977), but the most common allergic response is to eating soybean foods such as soy-based infant formulas (Halpern et al., 1973). The use of soy flours in milk replacers has long been known to cause gastrointestinal disturbances in calves. Recent work has attributed the disturbances to allergic responses caused by β-conglycinin and glycinin, the two major storage proteins (Kilshaw and Sissons, 1979). Heat treatment used in the normal preparation of soybean meal apparently is insufficient to eliminate the antigenicity of these proteins, whereas hot alcohol reportedly inactivates them (Sissons et al., 1982).

21-8.2.2 Structure-Function Relationships

Soy proteins in the form of flours, concentrates, and isolates are used as ingredients in the processing of a variety of foods ranging from baked goods to dairy analogs and processed meats. In some foods, they are major contributors of dietary protein (e.g., textured proteins used as meat extenders, meat analogs, and infant formulas), but most applications are for functional purposes where low levels of soy protein are often used.

Proteins in soybean are a complex mixture and commercial soy protein preparations reflect this complexity. Soy flours contain the naturally occurring mixture, whereas some of the minor proteins are removed in the preparation of concentrates and isolates. A major difference between the various soy proteins is molecular size, as revealed by ultracentrifugation (Table 21–15). The 7S and 11S fractions make up about 70% of the total protein. Six isomers of β-conglycinin are the major proteins found in the 7S fraction; they have a quaternary structure made up of three subunits (Thanh and Shibasaki, 1978) and are glycoproteins. The 11S fraction consists of 11S globulins or glycinins which likewise have a quaternary structure but consist of six subunits instead of three. Each glycinin subunit, in turn, contains an acidic (molecular wt. 37 000) and a basic (molecular wt. 20 000) polypeptide chain that are linked together by a disulfide bond. The complete amino acid sequence of one of the subunits is known (Staswick et al., 1984).

The quaternary structures of β-conglycinin and glycinin are sensitive to heat, pH, ionic strength, and organic solvents such as alcohols. Manipulation of these and other parameters can change the various functional properties of soy proteins that are summarized in Table 21–16. For example, depending upon conditions, heating can decrease solubility (Wolf and Tamura, 1969), increase foaming properties (Eldridge et al., 1963a) or induce gelation of soy proteins (Circle et al., 1964). Because of their differences in structure, β-conglycinin and glycinin also have other properties that set them apart from each other. Glycinin has solubility properties that are sensitive to temperature at low ionic strength and can be separated from β-conglycinin and the other proteins by cryoprecipitation (Wolf and Sly, 1967). The two proteins also differ in solubility as a function of pH. Glycinin has a minimum solubility at pH 6.7 whereas

Table 21–15. Approximate distribution of ultracentrifugal fractions of water-extractable soybean proteins (Wolf and Cowan, 1975).

Fraction	Amount of total	Components	Molecular wt	Other characteristics
	%			
2S	22	Trypsin inhibitors	8 000–21 500	Globulins
		Cytochrome C	12 000	Heme protein
7S	37	Hemagglutinins	11 000	Glycoproteins, albumins
		Lipoxygenases	102 000	Contain Fe
		β-Amylase	61 700	—
		β-Conglycinins	180 000–210 000	Glycoproteins, globulins, three subunits
11S	31	Glycinins	350 000	Globulins, six subunits
15S	10		>350 000	Polymer form of other proteins?

Table 21–16. Summary of functional properties of soy proteins important in food applications.†

Property	Functional criteria
Organoleptic/kinesthetic	Color, flavor, odor, texture, mouthfeel, smoothness, grittiness, and turbidity.
Hydration	Solubility, wettability, water absorption, swelling, thickening, and gelling syneresis.
Surface	Emulsification, foaming (aeration, whipping), protein-lipid, film formation, lipid-binding, and flavor-binding.
Structural/rheological	Elasticity, grittiness, cohesiveness, chewiness, viscosity, adhesion, network-crossbinding, aggregation, stickiness, gelation, dough formation, texturizability, fiber formation, and extrudability.
Other	Compatability with additives, enzymatic, and antioxidant.

†These properties vary with pH, temperature, protein concentration, protein fraction, prior treatment, ionic strength, and dielectric constant of the medium. They are also affected by other treatments, interactions with other macromolecules in the medium, by processing treatments and modification, by physical, chemical, or enzymatic methods (Kinsella, 1979).

β-conglycinin has its minimum in solubility at pH 5.0. These differences in solubility are used in conjunction with cryoprecipitation to separate β-conglycinin and glycinin from each other (Thanh and Shibasaki, 1976). Both proteins form gels on heating but the resulting gels differ in properties. Gels made from crude glycinin are higher in tensile and shear strength and have greater water-holding capacity than gels make from crude β-conglycinin (Saio et al., 1974).

Beta-Conglycinin and glycinin are not separated and available to the food industry on a commercial scale. However, the ratio of β-conglycinin to glycinin in different soybean varieties varies so that the ratio of the two proteins in isolates may be variable. Changes in the β-conglycinin: glycinin ratio result in differences in the physical properties of tofu. Tofu, made from soybean high in β-conglycinin content, is softer than tofu from soybean having a high content of glycinin (Saio et al., 1969).

Because of the variety of foods that soy proteins are used in, they must have a range of functional properties (Table 21–16). A given protein does not possess optimal functional properties for all uses. Processing is, therefore, tailored to modify functional properties to meet specific needs. Soy flours are processed with a range of moist heat treatments; for example, a light heat treatment gives a flour that is best suited for use in bread. Isolates, likewise, are modified by proprietary processes and are provided by the industry in different forms to meet specific applications. The chemistry of protein modification is still poorly understood, but a large literature on physical and chemical properties is now available (Smith and Circle, 1972; Kinsella, 1979).

21–8.2.2.1 Flavor and Color—Raw soybean has strong grassy-beany and bitter flavors and processing is necessary to remove or reduce them to acceptable levels. A large number of compounds has been isolated from soybean proteins; major compounds having flavor characteristics of soybeans are tabulated in Table 21–17. Except for the phenolic compounds (formed by decarboxylation of the corresponding cinnamic acids), all of these compounds are derived from lipids through enzymatic or chemical oxidation. These compounds are present at low concentrations (mg kg^{-1}) but interact strongly with the proteins making it difficult to remove them. Moist heat treatment is commonly used to remove or modify the flavor compounds in defatted soy flakes and flours, but bound forms of flavors persist and may be released later when the soy product is incorporated into a food and during mastication when the food is eaten. A combination of alcohol extraction and heat is used in the preparation of concentrates. Extraction of defatted flakes with a mixture of hexane/ethanol followed by toasting gives good results on a laboratory scale (Honig et al., 1976) and has been patented commercially for preparation of protein concentrates (Hayes and Simms, 1973), but may be too expensive to be competitive with regular moist heat treatment. A recent survey of commercial soy protein products indicated that residual flavors are still present (Warner et al., 1983).

Recognition that many of the flavors found in soybean products, particularly soy milk, may be generated enzymatically by lipoxygenase, resulted in development of the hot-grind procedure where lipoxygenase is inactivated during the initial grinding step which is carried out at 80°C or higher (Wilkens et al., 1967). This principle has been adopted by the Japanese soy milk industry although vacuum pan stripping is also included in processing to remove residual volatile flavor compounds (Shurtleff and Aoyagi, 1984).

Color of soybean protein products is less of a problem than flavor. Soy flours are cream to light yellow in color; increased heat treatment causes darkening probably because of browning reactions. Concentrates and isolates are cream colored. Extruded soy flours and concentrates are light to dark tan. The compounds responsible for the yellow color of soybean have not been identified. They are partially extractable with alcohol but concentrates prepared with alcohol still retain some yellow color. Alcohol washing of isolates removes some of the pigments (Eldridge et al., 1963b). Residual pigments appear to be firmly bound. Concentration of tan-brown pigments has been observed in the portion of isolates

Table 21–17. Compounds with flavor characteristics of soybean (Kinsella, 1979; Sessa et al., 1976).

Type	Specific compounds	Flavor characteristics
Alcohols	Isopentanol, hexanol, heptanol, octenol	Grassy, moldy, mushroom, musty
Aldehydes	Hexanal, heptenal, hexenal, decadienal	Grassy, potato chip-like
Ketones	Hexanone, ethyl vinyl ketone	Grassy-beany
Furans	2-Pentyl furan	Grassy-beany
Phenols	4-Vinylguaicol, 4-Vinylphenol	Cooked off-flavor
Phosphatides	Oxidized phosphatidylcholines	Bitter

that is irreversibly insolubilized by precipitation at pH 4.6, the so-called *acid-sensitive fraction* (Anderson and Warner, 1976).

21-9 FULL-FAT SOYBEAN PRODUCTS

Full-fat soy flour was manufactured for many years in the USA but was discontinued several years ago. It is, however, manufactured in Europe and some is imported into the USA. In England, enzyme active full-fat soy flour is added to virtually all bread (Pringle, 1974).

Soy milk has long been a dietary staple in China. With the introduction of modern processing techniques that have resulted in improved flavor of the product, however, soy milk has become a popular beverage in other parts of the Far East, and was imported into the USA in the early 1980s. Several companies were planning plants for the USA and conducting marketing studies in 1984 to 1985. In Japan, where soy milk has not been a traditional part of the diet, soy milk markets grew rapidly in the late 1970s and early 1980s. In 1983 to 1984, soy milk held about 5% of the Japanese market occupied by cow's milk (Haumann, 1984; Shurtleff and Aoyagi, 1984). Japanese consumers are buying soy milk primarily for health reasons—the desire to maintain a high proportion of plant foods in the diet and to avoid sources of cholesterol such as meat, eggs, and cow's milk. Four large food companies make about 80% of the soy milk produced in Japan.

Tofu became a popular item in the USA in the late 1970s. It is produced in small shops and several small factories and is available in many supermarkets. Long a staple in China and Japan, it became westernized and a wide range of recipes for its use has been developed (Shurtleff and Aoyagi, 1975).

Two fermented soybean foods, miso and tempeh, have also been introduced in the USA since the late 1970s. Miso, a paste-like product resembling peanut butter in consistency, is made by fermenting cooked soybean with salt with or without rice (*Oryza sativa* L.) or barley (*Hordeum vulgare* L.). In Japan, miso serves as a soup base but other uses for Western cuisine have been developed (Shurtleff and Aoyagi, 1976). Tempeh is made by inoculating cooked soybean with the mold, *Rhizopus oligosporus*, and fermenting for about 24 h. The mold mycellium permeates the bean mass and binds it together. When sliced and deep-fat fried, tempeh is crisp and golden brown; it is a traditional food of Indonesia (Shurtleff and Aoyagi, 1979).

REFERENCES

Allen, R.D. 1984. Feedstuffs ingredient analysis table: 1984 edition. Feedstuffs 56(30):25–30.

Allen, R.R. 1978. Principles and catalysts for hydrogenation of fats and oils. J. Am. Oil Chem. Soc. 55:792–795.

American Soybean Association. 1983. Soya bluebook. American Soybean Association, St. Louis.

——. 1984 Proceedings of the Ag-Chem Uses of soybean oil. American Soybean Association, St. Louis.

Anderson, R.L., and K. Warner. 1976. Acid-sensitive soy proteins affect flavor. J. Food Sci. 41:293–296.

Anonymous. 1963. Prepared salad dressings. Good Housekeeping 156(June):151.

——. 1982. Food fats and oils. Institute of Shortening and Edible Oils, Washington, DC.

Baker, E.C., and D.A. Sullivan. 1983. Development of a pilot-plant process for the extraction of soy flakes with aqueous isopropyl alcohol. J. Am. Oil Chem. Soc. 60:1271–1277.

Baldwin, R.R., R.P. Baldrey, and R.G. Johansen. 1972. Fat systems for bakery products. J. Am. Oil Chem. Soc. 49:473–477.

Barr, G. 1981. Soybean meal in calf milk replacers. J. Am. Oil Chem. Soc. 58:313–320.

Beal, R.E., E.B. Lancaster, and O.L. Brekke. 1956. The phosphorus content of refined soybean oil as a criterion of quality. J. Am. Oil Chem. Soc. 33:619–624.

Becker, K.W. 1978. Solvent extraction of soybeans. J. Am. Oil Chem. Soc. 55:754–761.

Bell, E.W., L.E. Gast, F.L. Thomas, and R.E. Koos. 1977. Sperm oil replacements: Synthetic wax esters from selectively hydrogenated soybean and linseed oils. J. Am. Oil Chem. Soc. 54:259–263.

Block, R.J., R.H. Mandl, H.W. Howard, C.D. Bauer, and D.W. Anderson. 1961. The curative action of iodine on soybean goiter and the changes in the distribution of iodoamino acids in the serum and in thyroid gland digests. Arch. Biochem. Biophys. 93:15–24.

Braae, B. 1976. Degumming and refining practices in Europe. J. Am. Oil Chem. Soc. 53:353–357.

Brekke, O.L. 1980. Oil degumming and soybean lecithin. p. 71–88. *In* D.R. Erickson et al. (ed.) Handbook of soy oil processing and utilization. American Soybean Association, St. Louis and American Oil Chemists' Society, Champaign, IL.

Broderick, G.A. 1975. Factors affecting ruminant responses to protected amino acids and proteins. p. 211–259. *In* M. Friedman (ed.) Protein nutritional quality of foods and feeds, Part 2. Marcel Dekker, New York.

Bureau of the Census. 1979. Current Industrial Report M 20K(79)–13.

Bush, R.K., and M. Cohen. 1977. Immediate and late onset asthma from occupational exposure to soybean dust. Clin. Allergy 7:369–373.

Calloway, D.H., C.A. Hickey, and E.L. Murphy. 1971. Reduction of intestinal gas-forming properties of legumes by traditional and experimental food processing methods. J. Food Sci. 36:251–255.

Carpenter, D.L., J. Lehmann, B.S. Mason, and H.T. Slover. 1976. Lipid composition of selected vegetable oils. J. Am. Oil Chem. Soc. 53:713–718.

Carr, R.A. 1978. Refining and degumming systems for edible fats and oils. J. Am. Oil Chem. Soc. 55:765–771.

Cheryan, M. 1980. Phytic acid interactions in food systems. CRC Crit. Rev. Food Sci. Nutr. 13:297–335.

Circle, S.J., E.W. Meyer, and R.W. Whitney. 1964. Rheology of soy protein dispersions. Effect of heat and other factors on gelation. Cereal Chem. 41:157–172.

Cline, T.R., D.L. Jones, and M.P. Plumlee. 1976. Use of condensed soybean solubles in nonruminant diets. J. Anim. Sci. 43:1015–1018.

Code of Federal Regulations. 1977a. Title 9:319.700 (Animal and Plant Health Inspection Service, USDA). U.S. Government Printing Office, Washington, DC.

——. 1977b. Title 21:166 (Food and Drugs). U.S. Government Printing Office, Washington, DC.

Coombes, W.A., R.A. Zavada, J.E. Hansen, W.A. Singleton, and R.R. King. 1974. Continuous hydrogenation of fatty materials. U.S. Patent 3 792 067. Date issued: 12 February.

Cowan, J.C. 1966. Key factors and recent advances in the flavor stability of soybean oil. J. Am. Oil Chem. Soc. 43:300A, 302A, 318A-321A.

Doell, B.H., C.J. Ebden, and C.A. Smith. 1981. Trypsin inhibitor activity of conventional foods which are a part of the British diet and some soya products. Qual. Plant. Plant Foods Hum. Nutr. 31:139–150.

Dufek, E.J., W.E. Parker, and R.E. Koos. 1974. Some esters of mono-, di-, and tricarboxysteric acid as lubricants: Preparation and evaluation. J. Am. Oil Chem. Soc. 51:351–355.

Dutton, H.J. 1981. History of the development of soy oil for edible uses. J. Am. Oil Chem. Soc. 58:234–236.

Eldridge, A.C., P.K. Hall, and W.J. Wolf. 1963a. Stable foams from unhydrolyzed soybean protein. Food Technol. 17:1592–1595.

----, J.P. Friedrich, K. Warner, and W.F. Kwolek. 1986. Preparation and evaluation of supercritical carbon dioxide defatted soybean flakes. J. of Food Sci. 51:584–587.

----, W.J. Wolf, A.M. Nash, and A.K. Smith. 1963b. Alcohol washing of soybean protein. J. Agric. Food Chem. 11:323–328.

Emken, E.A. 1985. Nutritional considerations in soybean oil usage. p. 242–250. *In* Richard Shibles (ed.) World soybean research conference III: Proceedings. Westview Press, Boulder, CO.

Engelman, H.W., D.A. Guenther, and T.W. Silvis. 1978. Vegetable oil as a diesel fuel. p. 1–8. *In* Am. Soc. Mech. Eng., Proc. Energy Technol. Conf. and Exhib., Houston, TX. 5–9 Nov. 1978.

Engster, H.M., N.A. Cave, H. Likuski, J.M. McNab, C.A. Parsons, and F.E. Pfaff. 1985. A collaborative study to evaluate a precision-fed rooster assay for true amino acid availability in feed ingredients. Poult. Sci. 64:487–498.

Erdman, J.W., Jr. 1979. Oilseed phytates: Nutritional implications. J. Am. Oil Chem. Soc. 56:736–741.

Flider, F.J. 1985. The manufacture of soybean lecithins. p. 21–37. *In* B.F. Szuhaj and G.R. List (ed.) Lecithins. American Oil Chemical Society, Champaign, IL.

Florin, G., and H.R. Bartesch. 1983. Processing of oilseeds using fluidbed technology. J. Am. Oil Chem. Soc. 60:193–197.

Frankel, E.N. 1980. Soybean oil flavor stability. p. 229–244. *In* D.R. Erickson et al. (ed.) Handbook of soy oil processing and utilization. American Soybean Association, St. Louis, and American Oil Chemists' Society, Champaign, IL.

----, P.M. Cooney, H.A. Moser, J.C. Cowan, and C.D. Evans. 1959. Effect of antioxidants and metal inactivators in tocopherol-free soybean oil. Fette Seifen Anstrichm. 61:1036–1039.

Freeman, I.P., F.B. Padley, and W.L. Sheppard. 1973. Use of silicones in frying oils. J. Am. Oil Chem. Soc. 50:101–103.

Friedrich, J.P., G.R. List, and A.J. Heakin, 1982. Petroleum-free extraction of oil from soybeans with supercritical CO_2. J. Am. Oil Chem. Soc. 59:288–292.

Gavin, A.M. 1983. Energy conservation in edible oil processing (U.S. view). J. Am. Oil Chem. Soc. 60:420–426.

Gumbmann, M.R., W.L. Spangler, G.M. Dugan, J.J. Rackis, and I.E. Liener. 1985. The USDA trypsin inhibitor study. IV. The chronic effects of soy flour and soy protein isolate on the pancreas in rats after two years. Qual. Plant. Plant Foods Hum. Nutr. 35:275–314.

Gunther, R.C. 1979. Chemistry and characteristics of enzyme-modified whipping proteins. J. Am. Oil Chem. Soc. 56:345–349.

Halpern, S.R., W.A. Sellars, R.B. Johnson, D.W. Anderson, S. Saperstein, and J.S. Reisch. 1973. Development of childhood allergy in infants fed breast, soy, or cow milk. J. Allergy Clin. Immunol. 51:139–151.

Harper, J.M. 1978. Food extrusion. CRC Crit. Rev. Food Sci. Nutr. 11:155–215.

Haumann, B.F. 1984. Soymilk—New processing, packaging expand markets. J. Am. Oil Chem. Soc. 61:1784–1786, 1788, 1790–1793.

Hayes, L.P., and R.P. Simms. 1973. Defatted soybean fractionation by solvent extraction. U.S. Patent 3 734 901. Date issued: 22 May.

Hoer, R.A. 1972. Protein fiber forming. U.S. Patent 3 662 672. Date issued: 16 May.

Honig, D.H., K. Warner, and J.J. Rackis. 1976. Toasting and hexane:ethanol extraction of defatted soy flakes. Flavor of flours, concentrates and isolates. J. Food Sci. 41:642–646.

Hymowitz, T., and J.R. Harlan. 1983. Introduction of soybean to North America by Samuel Bowen in 1765. Econ. Bot. 37:371–379.

Jensen, A.H. 1984. Dietary nutrient allowances for swine. Feedstuffs 56(30): 38, 40–41, 43.

Johnson, L.A., and E.W. Lusas. 1983. Comparison of alternative solvents for oils extraction. J. Am. Oil Chem. Soc. 60:229–242.

Jones, F.T. 1984. A survey of soybean meal used in poultry feeds 1976 to 1982. Poult. Sci. 63:1462–1463.

Kakade, M.L., D.E. Hoffa, and I.E. Liener. 1973. Contribution of trypsin inhibitors to the deleterious effects of unheated soybeans fed to rats. J. Nutr. 103:1772–1778.

Kawamura, S. 1967. Quantitative paper chromatography of sugars of the cotyledon, hull, and hypocotyl of soybeans of selected varieties. Tech. Bull. Fac. Agric. Kagawa Univ. 18:117–131.

Kilshaw, P.J., and J.W. Sissons. 1979. Gastrointestinal allergy to soyabean protein in preruminant calves. Allergenic constituents of soyabean products. Res. Vet. Sci. 27:366–371.

Kinsella, J.E. 1979. Functional properties of soy proteins. J. Am. Oil Chem. Soc. 56:242–258.

Kock, M. 1983. Oilseed pretreatment in connection with physical refining. J. Am. Oil Chem. Soc. 60:198–202.

Kornegay, E.T. 1978. Feeding value and digestibility of soybean hulls for swine. J. Anim. Sci. 47:1272–1280.

Kouzeh Kanani, M., D.J. van Zuilichem, J.P. Roozen, and W. Pilnik. 1984. A modified procedure for low temperature infrared radiation of soybeans: III. Pretreatment of whole beans in relation to oil quality and yield. Lebensm. Wiss. Technol. 17:39–41.

Lai, F.S., Y. Pomeranz, B.S. Miller, C.R. Martin, D.F. Aldis, and C.S. Chang. 1981. Status of research on grain dust. Adv. Cereal Sci. Technol. 4:237–337.

Landfried, B.W. 1977. Surfactants used by bread makers. Cereal Foods World 22:338–340.

Lawhon, J.T., L.J. Manak, K.C. Rhee, K.S. Rhee, and E.W. Lusas. 1981. Combining aqueous extraction and membrane isolation techniques to recover protein and oil from soybeans. J. Food Sci. 46:912–916, 919.

Lebrun, A., M. Knott, and J. Beheray. 1985. Meal desolventizing and finishing. J. Am. Oil Chem. Soc. 62:793–799.

Liener, I.E. 1981. Factors affecting the nutritional quality of soya products. J. Am. Oil Chem. Soc. 58:406–415.

——, Z. Nitsan, C. Srisangnam, J.J. Rackis, and M.R. Gumbmann. 1985. The USDA trypsin inhibitor study. II. Time related biochemical changes in the pancreas of rats. Qual. Plant. Plant Foods Hum. Nutr. 35:243–257.

Link, W.E. (ed). 1975. Official and tentative methods. 3rd ed. American Oil Chemists' Society, Champaign, IL.

List, G.R., C.D. Evans, K. Warner, R.E. Beal, W.F. Kwolek, L.T. Black, and K.J. Moulton. 1977. Quality of oil from damaged soybeans. J. Am. Oil Chem. Soc. 54:8–14.

——, T.L. Mounts, and A.J. Heakin. 1978a. Steam-refined soybean oil: II. Effect of degumming methods on removal of prooxidants and phospholipids. J. Am. Oil Chem. Soc. 55:280–284.

——, ——, K. Warner, and A.J. Heakin. 1978b. Steam-refined soybean oil: I. Effect of refining and degumming methods on oil quality. J. Am. Oil Chem. Soc. 55:277–279.

Lonnerdal, B., A. Cederblad, L. Davidsson, and B. Sandstrom. 1984. The effect of individual components of soy formula and cows' milk formula on zinc bioavailability. Am. J. Clin. Nutr. 40:1064–1070.

Lorenz, K. 1978. Dimethyl polysiloxanes in baking and frying fats and oils. Baker's Dig. 52(2):36–40, 69.

Lyman, R.L. 1957. The effect of raw soybean meal and trypsin inhibitor diets on the intestinal and pancreatic nitrogen in the rat. J. Nutr. 62:285–294.

Massiello, F.J. 1978. Changing trends in consumer margarines. J. Am. Oil Chem. Soc. 55:262–265.

McGuinness, E.S., R.G.H. Morgan, D.A. Levison, D.L. Frape, G. Hopwood, and K.G. Wormsley. 1980. The effects of long-term feeding of soya flour on the rat pancreas. Scand. J. Gastroenterol. 15:497–502.

McNaughton, J.L. 1981. Color, trypsin inhibitor and urease activity as it affects growth of broilers. J. Am. Oil Chem. Soc. 58:321–324.

Milligan, E.D., and J.F. Suriano. 1974. System for production of high and low protein dispersibility index edible extracted soybean flakes. J. Am. Oil Chem. Soc. 51:158–161.

Miyakoshi, K., and M. Komoda. 1978. Effect of deodorizing and heating conditions on the content of citric acid and its decomposed products in edible oils. Yukagaku 27:381–384.

Mogush, J.J. 1980. Soybean processing industry—U.S. and foreign. p. 889–896. *In* F.T. Corbin (ed) World soybean research conference II: Proceedings. Westview Press, Boulder, CO.

Moore, N.H. 1983. Oilseed handling and preparation prior to solvent extraction. J. Am. Oil Chem. Soc. 60:189–192.

Moser, H.A., H.J. Dutton, C.D. Evans, and J.C. Cowan. 1950. Conducting a taste panel for the evaluation of edible oils. Food Technol. 4:105–109.

——, C.D. Evans, J.C. Cowan, and W.F. Kwolek. 1965. A light test to measure stability of edible oils. J. Am. Oil Chem. Soc. 42:30–33.

——, C.M. Jaeger, J.C. Cowan, and H.J. Dutton. 1947. The flavor problem of soybean oil: II. Organoleptic evaluation. J. Am. Oil Chem. Soc. 24:291–296.

Mounts, T.L., K.A. Warner, G.R. List, J.P. Friedrich, and S. Koritala. 1978. Flavor and oxidative stability of hydrogenated and unhydrogenated soybean oils: Effects of antioxidants. J. Am. Oil Chem. Soc. 55:345–349.

Moustafa, A. 1979. Soft margarine in the U.S.A. Report prepared for the American Soybean Association, St. Louis.

Mustakas, G.C. 1980. Recovery of oil from soybeans. p. 49–65. *In* D.R. Erickson et al. (ed.) Handbook of soy oil processing and utilization. American Soybean Association, St. Louis and American Oil Chemists Society, Champaign, IL.

——, L.D. Kirk, and E.L. Griffin, Jr. 1962. Flash desolventizing defatted soybean meals washed with aqueous alcohols to yield a high-protein product. J. Am. Oil Chem. Soc. 39:222–226.

——, E.D. Milligan, J. Taborga A., and D.A. Fellers. 1980. Conversion of soybean extraction plant in Bolivia to production of flours for human consumption: Feasibility study. J. Am. Oil Chem. Soc. 57:55–58.

Myers, N.W. 1957. Design and operation of a commercial soybean-oil refining plant using acetic anhydride as a degumming reagent. J. Am. Oil Chem. Soc. 34:93–96.

Nash, N.H., and L.M. Brickman. 1972. Food emulsifiers—science and art. J. Am. Oil Chem. Soc. 49:457–461.

National Soybean Processors Association. 1984–1985. Yearbook and trading rules. National Soybean Processors Association, Washington, DC.

Newkirk, D.R., A.J. Shephard, and W.D. Hubbard. 1978. Comparison of total fat, fatty acids, cholesterol, and other sterols in mayonnaise and imitation mayonnaise. J. Am. Oil Chem. Soc. 55:548A-549A.

Numenz, G.M. 1978. Old and new in winterizing. J. Am. Oil Chem. Soc. 55:396A-398A.

Ohlrogge, J.B., R.M. Gulley, and E.A. Emken. 1982. Occurrence of octadecenoic fatty acid isomers from hydrogenated fats in human tissue lipid classes. Lipids 17:551–557.

Osborne, T.B., and L.B. Mendel. 1917. The use of soy bean as food. J. Biol. Chem. 32:369–387.

Perkins, R.B., Jr., J.J. Roden, III, and E.H. Pryde. 1975. Nylon-9 from unsaturated fatty derivatives: Preparation and characterization. J. Am. Oil Chem. Soc. 52:473–477.

Powell, T.S., and M.H. Gehle. 1976. Effect of various pullet restriction methods on performance of broiler breeders. Poult. Sci. 55:502–509.

Pringle, W. 1974. Full-fat soy flour. J. Am. Oil Chem. Soc. 51:74A-76A.

Probst, A.H., and R.W. Judd. 1973. Origin, U.S. history and development, and world distribution. *In* B.E. Caldwell (ed.) Soybeans: improvement, production, and uses. 16:1–15.

Pryde, E.H. 1980. Composition of soybean oil. p. 13–31. *In* D.R. Erickson et al. (ed.) Handbook of soy oil processing and utilization. American Soybean Association, St. Louis, and American Oil Chemists Society, Champaign, IL.

——. 1983. Utilization of commercial oilseed crops. Econ. Bot. 37:459–477.

Rackis, J.J. 1981. Flatulence caused by soya and its control through processing. J. Am. Oil Chem. Soc. 58:503–509.

Rizek, R.L., S.O. Welsh, R.M. Marston, and E.M. Jackson. 1983. Levels and sources of fat in the U.S. food supply and in diets of individuals. p. 13–43. *In* E.G. Perkins and W.H. Visek (ed.) Dietary fats and health. American Oil Chemists Society, Champaign, IL.

Rudolph, B.C., L.S. Boggs, D.A. Knabe, T.D. Tanksley, Jr., and S.A. Anderson, 1983. Digestibility of nitrogen and amino acids in soybean products for pigs. J. Anim. Sci. 57:373–386.

Saio, K., M. Kamiya, and T. Watanabe. 1969. Food processing characteristics of soybean 11S and 7S proteins. Part I. Effect of difference of protein components among soybean varieties on formation of tofu-gel. Agric. Biol. Chem. 33:1301–1308.

——, I. Sato, and T. Watanabe. 1974. Food use of soybean 7S and 11S proteins. High temperature expansion characteristics of gels. J. Food Sci. 39:777–782.

Sair, L. 1959. Proteinaceous soy composition and method of preparing. U.S. Patent 2 881 076. Date issued: 7 April.

Schneider, W.J., and L.E. Gast. 1978. Water-dispersible urethane polyesteramide coatings from linseed oil. J. Coat. Technol. 50(646):76–81.

——, and ——. 1979. Poly(ester-amide-urethane) water dispersible and emulsifiable resins. J. Coat. Technol. 51(654):53–57.

Schwab, A.W., W.K. Rohwedder, and L.E. Gast. 1978. Hydrogen sulfide adducts of methyl trans,trans-9,11-octadecadienoate. J. Am. Oil Chem. Soc. 55:860–864.

Scott, M.L. 1984. Dietary nutrient allowances for chickens, turkeys. Feedstuffs 56(30): 64, 66.

Sessa, D.J., K. Warner, and J.J. Rackis. 1976. Oxidized phosphatidylcholines from defatted soybean flakes taste bitter. J. Agric. Food Chem. 24:16–21.

Shurtleff, W., and A. Aoyagi. 1975. The book of tofu, Vol. 1. Autumn Press, Hayama-shi, Kanagawa-ken, Japan.

——, and ——. 1976. The book of miso. Autumn Press, Brookline, MA.

——, and ——. 1979. The book of tempeh. Harper and Row Publishing, New York.

——, and ——. 1984. Soymilk. Industry and market. The Soyfoods Center, Lafayette, CA.

Sievert, C.W. 1972. Formulating quality feeds. p. 103–136. *In* Feed industry red book. Communications Marketing, Edina, MN.

Sissons, J.W., A. Nyrup, P.J. Kilshaw, and R.H. Smith. 1982. Ethanol denaturation of soya bean protein antigens. J. Sci. Food Agric. 33:706–710.

Smith, A.K., and S.J. Circle. 1972. Soybeans: Chemistry and technology, Vol. I. Proteins. AVI Publishing Co., Westport, CT.

Spears, J.W., J.H. Clark, and E.E. Hatfield. 1985. Nitrogen utilization and ruminal fermentation in steers fed soybean meal treated with formaldehyde. J. Anim. Sci. 60:1072–1080.

Staswick, P.E., M.A. Hermodson, and N.C. Nielsen. 1984. The amino acid sequence of the A_2B_{1a} subunit of glycinin. J. Biol. Chem. 259:13424–13430.

Steggerda, F.R., E.A. Richards, and J.J. Rackis. 1966. Effects of various soybean products on flatulence in the adult man. Proc. Soc. Exp. Biol. Med. 121:1235–1239.

Sullivan, D.A., B.D. Campbell, M.F. Conway, and F.N. Grimsby. 1982. Isopropanol extraction of oilseeds. Oil Mill Gazet. 86(10):24–27.

Sullivan, F.E. 1976. Steam refining. J. Am. Oil Chem. Soc. 53:358–360.

Szuhaj, B.F. 1980. Food and industrial uses of soybean lecithin. p. 681–691. *In* F.T. Corbin (ed.) World soybean research conference II: Proceedings. Westview Press, Boulder, CO.

——, and G.R. List (ed.) 1985. Lecithins. American Oil Chemists Society, Champaign, IL.

Thanh, V.H., and K. Shibasaki. 1976. Major proteins of soybean seeds. A straightforward fractionation and their characterization. J. Agric. Food Chem. 24:1117–1121.

——, and ——. 1978. Major proteins of soybean seeds. Subunit structure of β-conglycinin. J. Agric. Food Chem. 26:692–695.

Thomas, F.L., and L.E. Gast. 1979. New solventless polymeric protective coatings from fatty acid derivatives. J. Coat. Technol. 51(657):51–59.

Thulin, W.W., and S. Kuramoto. 1967. "Bontrae"—A new meat-like ingredient for convenience foods. Food Technol. 21:168–171.

Turner, R.H., and I.E. Liener. 1975. The effect of the selective removal of hemagglutinins on the nutritive value of soybeans. J. Agric. Food Chem. 23:484–487.

Turnlund, J.R., J.C. King, W.R. Keyes, B. Gong, and M.C. Michel. 1984. A stable isotope study of zinc absorption in young men: Effects of phytate and α-cellulose. Am. J. Clin. Nutr. 40:1071–1077.

U.S. Department of Agriculture. 1950–1982. Agricultural statistics. USDA-ERS, U.S. Government Printing Office, Washington, DC.

——. 1983. Proceedings of vegetable oil as diesel fuel—Seminar III. USDA-ARS, ARM-NC28, Oct. 19–20. U.S. Government Printing Office, Washington, DC.

——. 1984a. U.S. soybean industry. ERS, Agric. Econ. Rep.

——. 1984b. Feed. Outlook and situation report. p. 37–39. USDA-ERS FdS-295. U.S. Government Printing Office, Washington, DC.

——. 1984c. Oil crops. Outlook and situation report. USDA-ERS OCS-6, U.S. Government Printing Office, Washington, DC.

Vandergrift, W.L., D.A. Knabe, T.D. Tanksely, Jr., and S.A. Anderson. 1983. Digestibility of nutrients in raw and heated soyflakes for pigs. J. Anim. Sci. 57:1215–1224.

Van Nieuwenhuyzen, W. 1976. Lecithin production and properties. J. Am. Oil Chem. Soc. 53:425–427.

Warner, K., T.L. Mounts, J.J. Rackis, and W.J. Wolf. 1983. Relationships of sensory characteristics and gas chromatographic profiles of soybean protein products. Cereal Chem. 60:102–106.

Watt, B.K., and A.L. Merrill. 1963. Composition of foods. USDA Agric. Handb. 8. U.S. Government Printing Office, Washington, DC.

Weihrauch, J.L., C.A. Brignoli, J.B. Reeves, III, and J.L. Iverson. 1977. Fatty acid composition of margarines, processed fats and oils: A new compilation of data for tables of food composition. Food Technol. 31(2):80–85, 91.

Weiss, T.J. 1983. Mayonnaise and salad dressings. p. 211–246. *In* Food oils and their uses. 2d ed. AVI Publishing Co., Westport, CT.

Wiedermann, L.H. 1978. Margarine and margarine oil, formulation and control. J. Am. Oil Chem. Soc. 55:823–829.

———. 1981. Degumming, refining and bleaching soybean oil. J. Am. Oil Chem. Soc. 58:159–166.

Wilkins, W.F., L.R. Mattick, and D.B. Hand. 1967. Effect of processing method on oxidative off-flavors of soybean milk. Food Technol. 21:1630–1633.

Williams, T.A. 1899. The soybean as a forage crop. USDA Farmers' Bull. 58.

Wolf, W.J., and J.C. Cowan. 1975. Soybeans as a food source. CRC Press, Cleveland.

———, and D.A. Sly. 1967. Cryoprecipitation of soybean 11S protein. Cereal Chem. 4:653–668.

———, and T. Tamura. 1969. Heat denaturation of soybean 11S protein. Cereal Chem. 46:331–344.

Zehnder, C.T. 1976. Deodorization 1975. J. Am. Oil Chem. Soc. 53:364–369.